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Emission Characterization of a Spark-Ignited Heavy-Duty Direct-Injected Methanol Engine

Southwest Research Inst.
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16. ABSTRACT

Maschninenfabrik Augsburg-Nuernberg (M.A.N.) of Germany has modified a truck-size diesel engine to consume only neat methanol by the addition of a transistorized spark ignition system. Regulated and unregulated exhaust emissions from this methanol engine with oxidation catalyst were characterized over the 1979 13-mode Federal Test Procedure (FTP), or shorter versions of this modal test, and over the 1984 Transient Heavy-Duty FTP. Emissions characterization included regulated emissions (HC, CO, and NO_x), along with unburned alcohols, aldehydes, other gaseous organics, total particulate, sulfate, soluble organic in particulate, BaP, and Ames bioactivity. Emissions from this spark-ignited methanol-and-catalyst engine were compared to emissions from a pilot-injected methanol engine (dual-fueled) and a comparable diesel engine.

Very low levels of HC, aldehydes, other hydrocarbon-like species, and total particulate were observed for the spark-ignited catalyst engine. No carbon soot or smoke opacity was noted for this neat methanol fueled engine and both BaP content and Ames response of the soluble organic fraction (SOF) was very low. SOF for this spark-ignited engine appears to have originated from the engine oil, on the basis of boiling point distribution.

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FOREWORD

The project on which this report is based was initiated by Work Assignment No. 2 of EPA Contract 68-03-3073, received by SwRI on December 1, 1981. The contract was for "Pollutant Assessment Support for the Emission Control Technology Division." Work Assignment No. 2 of that contract was specifically for "M.A.N. Methanol Engine Characterization." The work was identified within SwRI as Project No. 05-6619-002.

The Project Officer and the Technical Project Monitor for EPA's Technology Assessment Branch during the Work Assignment were Mr. Robert J. Garbe and Mr. Thomas M. Baines, respectively. SwRI Project Director was Mr. Karl J. Springer, and SwRI Project Manager was Mr. Charles T. Hare. The SwRI Task Leader and principal investigator for the Work Assignment No. 2 effort was Mr. Terry L. Ullman. Lead technical personnel were Mr. Gregory W. Boyd and Mr. Patrick Medola.

We would like to express our appreciation to Maschinenfabrik Augsburg-Nuernberg of Germany for supplying the prototype methanol engine. We especially appreciate the direction and assistance of Mr. F. Chmela of M.A.N.

ABSTRACT

The uncertainty of petroleum-based fuel availability has created a need for diversifying into alternate fuels. Maschninenfabrik Augsburg-Nurnberg (M.A.N.) of Germany has modified a truck-size diesel engine to consume solely neat methanol by the addition of a transistorized spark ignition system. This approach is attractive because it required no new technology, and because the energy efficiency of the diesel engine is retained essentially intact while consuming low-cetane fuels.

Exhaust emissions from this methanol engine with oxidation catalysts were characterized over the 1979 13-mode Federal Test Procedure (FTP), or shorter versions of this modal test, and over the 1984 Transient Heavy-Duty FTP. Emissions characterization included regulated emissions (HC, CO, and NO_x) along with total particulate, unburned alcohols, individual hydrocarbons, aldehydes, phenols, and odor. The particulate matter was characterized in terms of particle size distribution, C, H, S, metal content, and soluble organic fraction. The soluble organic fraction was further studied by determining its elemental composition (C, H, S, N), boiling point distribution, BaP content, relative make-up of polar compounds, and bioactivity by Ames testing.

Very low levels of HC, aldehydes and other hydrocarbon-like species were observed. In addition, particulate emissions were extremely low. Most of the observed particulate emission (70%) was composed of soluble organic matter which had a relatively low BaP content and low Ames response. Regulated and unregulated emissions from this spark-ignited methanol-and-catalyst engine were compared to emissions from a pilot-injected methanol engine and a comparable diesel engine.

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I. INTRODUCTION

Worldwide dependence on petroleum products and associated economic and environmental problems have become quite apparent over the last decade. Current dependence on and uncertainty of petroleum-based fuel availability for transportation and production of goods and services has created a need for diversifying into alternative fuels. Alcohols constitute a renewable fuel source which has been available for years, but which has not been used as primary engine fuel because petroleum distillates were less expensive to produce. Maschinenfabrik Augsburg-Nurnberg (M.A.N.) of West Germany has developed a spark-ignited "diesel" engine which can utilize neat alcohols.(1)* The approach represented by this engine is attractive because it required no new technology, and because the energy efficiency of the converted engine is retained essentially intact. It has been uncertain what effects the use of alternative fuels will have on mobile source emissions, particularly those which are currently unregulated. Lower emissions of smoke and NO_x, already reported in the literature, make alcohol fuels appear to be attractive diesel fuel alternatives.(1,2)

The objective of this work was to characterize the emissions behavior of the M.A.N. truck-size (147 kW at 2200 rpm) naturally aspirated, 6-cylinder, spark-ignited, direct-injected methanol engine using an oxidation catalyst. Results from emissions characterization of this engine, designated as M.A.N. D2566 FMUH, were compared to emissions from a diesel pilot-injected methanol engine tested with and without oxidation catalyst, and a comparable diesel engine.

The exhaust from the M.A.N. methanol engine was characterized in varying degrees over the 1979 13-mode Federal Test Procedure (FTP), or shorter versions of this modal test, and over the 1984 Transient Heavy-Duty FTP. Emissions characterization in this program included regulated emissions (HC, CO, NO_x and smoke) along with total particulate, unburned methanol, individual hydrocarbons, aldehydes, phenols, and odor. The total particulate matter was characterized in terms of particle size distribution, C, H, S, metals content, and soluble organic fraction. The soluble organic fraction was further studied by determining its BaP content, bioactivity by Ames testing, boiling point distribution, relative make-up of polar compounds, and its elemental content (C, H, N).

The 13-mode FTP is currently used for regulating heavy-duty diesel emissions. The Transient Heavy-Duty FTP will be optional for the 1984 model year, and will be mandatory by 1985. The 1986 proposed transient FTP includes both gaseous and particulate emission measurement and regulation. Thirteen-mode FTP emission measurements were conducted during individual modes of steady-state operation. Transient FTP emission measurements were conducted during both cold-start and hot-start cycles.

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*Numbers in parentheses designate references at the end of this report.

II. SUMMARY

Maschinenfabrik Augsburg-Nurnberg (M.A.N.) of West Germany has converted a horizontal in-line 6 cylinder compression-ignition diesel engine into a spark-ignited, direct-injected engine capable of consuming neat methanol.(1) This naturally aspirated alternate fuel engine utilized an oxidation catalyst for exhaust aftertreatment, and produced 147 kW at 2200 rpm with 77 kg/hr of methanol. The use of methanol fuel in this engine produced no visible smoke, allowing high rates of fueling at low engine speeds which resulted in a maximum torque of 836 N•m (612 ft lb) at 1000 rpm.(3) Although the engine performed well over both steady-state and transient testing, some problems with spark ignition system component durability were encountered.

Emissions from this methanol-fueled heavy-duty direct-injected engine were characterized over the 1979 13-mode and 1984 Transient Federal Test Procedures for heavy-duty diesel engines, as well as a 7-mode test based on the 13-mode procedure. Table 1 summarizes the composite results for regulated and unregulated emissions from this engine. Emission results from a Volvo diesel pilot-injected engine characterized in methanol and methanol-catalyst configurations, along with those of a comparable diesel engine (from previous EPA Contract No. 68-03-2884, Task No. 6), are included in Table 1 for comparison to the spark-ignited M.A.N. methanol-catalyst engine.(4) In addition, HC, CO and NO_x emissions from a comparable M.A.N. diesel engine (Model D2566 MLUM) over the 13-mode test procedure are given in footnote "h" of Table 1.

On the basis of computing exhaust hydrocarbons using a molecular weight of 13.77 per carbon atom, the hydrocarbon mass emissions from the M.A.N. spark-ignited engine were very low over both test procedures. The hydrocarbon mass emission over the 13-mode test procedure was only about a fifth of that reported for a M.A.N. D2566 MLUM Diesel engine. Specialized measurement and analysis techniques for unregulated emissions indicated substantial emissions of unburned methanol during low power steady-state conditions, and over transient testing. Significant emissions of formaldelyde were noted over low power steady-state operation, but not during transient operation. Methane emissions were noted during steady-state and transient operation, but were at or below the background levels of the engine intake air (2.2 ppmC). No phenols above the minimum detectable concentrations were noted over transient operation. Summation of these individually-determined composites of exhaust hydrocarbon emissions yielded composite total hydrocarbons of 0.59 g/kW-hr over 7-modes of steady-state operation and 0.91 g/kW-hr over cold- and hot-start transient operation. These hydrocarbon levels are well below the Federally regulated 1984 13-mode limit of 0.67 g/kW-hr and the 1984 Transient limit of 1.74 g/kW-hr. The bulk of these hydrocarbons were made up of unburned methanol. The

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TABLE 1. SUMMARY OF COMPOSITE EMISSION RATES FROM THE DIESEL AND METHANOL-FUELED ENGINES

	Engine Test Configuration							
Composite Emission Rates	Spark-Ignited Methanol-Catalyst M.A.N. D2566 FMUH		Conventional Diesel Volvo TD-100C		Pilot-Injected Methanol Volvo TD-100A		Pilot-Injected Methanol-Catalyst Volvo TD-100A	
Federal Test Procedure (FTP)	13-Mode	Transient	13-Mode	Transient	13-Mode	Transient	13-Mode^{h}	Transient^{i}
Hydrocarbons, HC^{a} g/kW-hr, (g/hp-hr)	0.24^{h} (0.18)	0.06 (0.04)	1.05 (0.78)	1.15 (0.85)	1.45 (1.08)	1.95 (1.45)	0.16 (0.12)	0.16 (0.12)
Carbon Monoxide, CO g/kW-hr, (g/hp-hr)	0.39^{h} (0.29)	0.42 (0.31)	3.18 (2.37)	4.04 (3.01)	9.55 (7.12)	10.29 (7.67)	0.83 (0.62)	3.61 (2.69)
Oxides of Nitrogen, NO_x^{b} g/kW-hr (g/hp-hr)	9.13^{h} (6.81)	8.86 (6.61)	11.88^{e} (8.86)	11.19 (8.34)	5.26 (3.92)	7.31 (5.45)	6.79 (5.06)	7.39 (5.51)
Brake Specific Fuel Consumption kg fuel/kW-hr,^{c} (kg diesel/kW-hr)^{d}	0.624 (0.287)	0.708 (0.326)	0.262 (0.262)	0.288 (0.288)	0.486 (0.289)	0.531 (0.297)	0.482 (0.287)	0.518 (0.295)
Test Cycle	7-Mode	Transient	7-Mode	Transient	7-Mode	Transient	7-Mode	Transient
Total Individual HC mg/kW-hr	0	1.1	120	130	67	180	32	66
Total Unburned Alcohols mg/kW-hr	530	910	Does not Apply	Does Not Apply	2200	4900	950	890
Total Aldehydes mg/kW-hr	61	<1.1	16	14	88	250	140	260
Total Phenols mg/kW-hr	Not Run	0	Not Run	35	17	24	14	48
Σ of Hydrocarbon Species g/kW-hr, (g/hp-hr)	0.59 (0.44)	0.91 (0.68)	1.07 (0.80)	1.16 (0.87)	2.37 (1.77)	5.35 (3.99)	1.14 (0.85)	1.26 (0.94)
Total Particulate g/kW-hr, (g/hp-hr)	0.024 (0.018)	0.057 (0.043)	0.69 (0.52)	0.70 (0.52)	0.30 (0.23)	0.39 (0.30)	0.51 (0.38)	0.37 (0.27)
Sulfate, $SO_4^{=}$ mg/kW-hr, (% of Particulate)	Not Run	Not Run	45 (6.5%)	38 (5.4%)	14 (4.6%)	16 (4.1%)	220 (43%)	98 (27%)
Soluble Organic Fraction (SOF) mg/kW-hr, (% of Particulate)	14 (59%)	43 (75%)	200 (28%)	220 (32%)	200 (66%)	280 (73%)	70 (14%)	60 (16%)
BaP µg/kW-hr	0.06	0.03	0.64	3.7	0.86	1.7	0.08	0.33
Ames Response^{f} (revertant/plate×10^{3})/kW-hr	$8.3^{3,g}$	21^{3}	490^{2}	580^{2}	310^{2}	510^{1} 180^{2}	120^{2}	710^{1}

[a] HC values on HFID and computed as diesel-like species - see Σ of Hydrocarbons for actual total hydrocarbons

[b] No NO_x correction factor applied to either 13-mode or transient results

[c] Computed on basis of measured diesel and alcohol consumption

[d] Computed on basis of equivalent diesel by lower heating values

[e] NO_x value is reduced to 10.89 g/kW-hr (8.12 g/hp-hr) when the intake humidity correction for NO_x is applied

[f] Average of brake specific response with and without metabolic activation from all 5 strains. Superscript refers to the order of sample submittal and testing

[g] Composite Response from strain TA98 only

[h] Emissions from a M.A.N. D2566 MLUM over the 13-mode test procedure were: HC, 1.11 g/kW-hr (0.83 g/hp-hr); CO, 3.12 g/kW-hr (2.33 g/hp-hr); and NO_x, 8.66 g/kW-hr (6.46 g/hp-hr) (data supplied by M.A.N.)

importance of methanol as a pollutant relative to other hydrocarbon emissions which make up the total is an unanswered question, but one of importance concerning the regulation of hydrocarbon emissions when alternate fuels are used.

Carbon monoxide emissions over both test procedures were very low, due to the oxidation catalyst, and were only about 2 percent of the 1984 Federal emission standard level of 20.8 g/kW-hr. The CO mass emission over the 13-mode test procedure was only one-eighth of that reported for the M.A.N. D2566 MLUM diesel engine. NO_x emissions over both test procedures were similar, and were 24 percent below the 1984 13-mode regulated level of 12.1 g/kW-hr and 38 percent below the 1984 Transient regulated level of 14.3 g/kW-hr. The NO_x emissions from the spark-ignited engine, over the 13-mode FTP, were about 2.3 percent above the level reported for the M.A.N. D2566 DLUM diesel engine.

Although no smoke opacity was observed during any warm engine operation, particulate emissions were noted. Particulate emissions were extremely low, however, and no carbon black was noted on any of the filter media used for collection purposes. Approximately 83 percent of the particles were less than 0.6 μm aerodynamic diameter as determined by cascade impactor. Of the low levels of total particulate emitted, almost 70 percent was soluble organic material. On the basis of comparative boiling point distribution data, the SOF appears to be similar to the crankcase oil. Even though only methanol was consumed, low levels of BaP were noted, and the bioactivity of the soluble fraction was low. Comparisons between the emissions from the M.A.N. spark-ignited methanol-catalyst engine and those obtained from a diesel engine and the pilot-injected methanol engine with and without catalyst are detailed in Section V of the text and are summarized here.

Actual total hydrocarbons from the pilot-injected methanol engine were significantly higher than for its diesel counterpart due to substantial emissions of unburned methanol, aldheydes, and other HC species. The addition of a catalyst to the pilot-injected methanol engine reduced emissions of actual total hydrocarbons by reducing unburned methanol, but in some modes of operations, greater aldehyde emissions were apparent. Using only methanol, the spark-ignited engine with catalytic aftertreatment produced even lower total hydrocarbon emissions. Although the level of unburned methanol was similar to levels obtained for the pilot-injected methanol-catalyst configuration, steady-state aldehydes were very low, but still higher than for the diesel engine. Practically no aldehydes were noted for transient testing on the spark-ignited engine.

Carbon monoxide from the pilot-injected methanol engine was substantially higher than that obtained from the diesel counterpart. Although significant reduction of CO emissions was observed with the addition of the catalyst, the CO levels obtained from the spark-ignited methanol-catalyst engine were even lower. Substantial reductions from the diesel NO_x emission level were obtained with the pilot-injected methanol engine configuration. Although steady-state NO_x appeared to increase when the catalyst was used, the lower NO_x measured without the catalyst may have been influenced by instrument interference of methanol fuel-like species.

Total particulate and sulfate from the pilot-injected methanol engine were significantly reduced, but the level of SOF remained about the same as for the diesel engine. Compared to the diesel engine, BaP and bioactivity were generally lower for the pilot-injected methanol engine. Addition of the catalyst to the pilot-injected engine did not reduce total particulate, due to increased sulfate emission offset by reductions in SOF. The catalyst did reduce the level of BaP. Addition of the catalyst to the pilot-injected methanol configuration increased Ames response over transient operation, but reduced Ames response over steady-state operation. Since only methanol was consumed in the spark-ignited engine, its particulate emissions were only one-tenth those of the diesel engine, and were well below the 1986 proposed standard of 0.34 g/kW-hr. With no carbon soot or sulfate, the bulk of the particulate was SOF, which had lower BaP content and response to Ames testing than that from the diesel engine.

III. TEST PLAN AND DESCRIPTION OF ENGINE, FUEL AND PROCEDURES

The intent of this program was to characterize regulated gaseous emissions along with particulate and unregulated emissions from a M.A.N. D2566 FMUH methanol engine using an oxidation catalyst for exhaust aftertreatment. This section describes the test plan used in the program. Some of the pertinent engine specifications and a description of the oxidation catalyst will be presented. Properties for the neat methanol fuel and the lubricating oil will also be given. Procedures are described, including both the test procedures used to generate and acquire emission samples and the analytical procedures used to characterize the emission samples.

A. Test Plan

The planned program included emission measurements of both regulated and unregulated emissions from the engine in an "as-received" baseline configuration. The engine was tested over both steady-state and transient operation. Table 2 illustrates the extent of emissions characterization performed. Since the M.A.N. engine consumed only methanol, it was anticipated that particulate levels would be low and collection of particulate samples over steady-state modes was limited to 2 hours. In the case of transient testing, multiple runs for particulate collection were limited to 2 cold-starts and 12 hot-starts. Subsequent analysis of the resulting particulate extractables were prioritized in order to obtain the most useful information from limited quantities of extractables. Provisions to extract blank filters were made in the event that extractable rates were low. Analysis of this blank filter extract was conducted to account for any "background" contribution to the analysis of the particulate extractables. In addition to the analyses listed in Table 2, regulated emissions were measured before and after the catalyst during a 13-mode FTP.

B. Description of Test Engine

Figures 1 and 2 show the M.A.N. D2566 methanol engine mounted as operated on a transient-capable stationary dynamometer. This heavy-duty methanol-fueled test engine was adapted from a diesel engine version normally used in buses. The horizontal 6-cylinder in-line configuration was modified for neat methanol consumption by the addition of a transistorized spark-ignition system. This naturally-aspirated engine developed 147 kW at 2200 rpm with a fuel flow of 77 kg methanol per hour. Some of the specifications for this engine are given in Table 3.(3)

TABLE 2. PLANNED EMISSION MEASUREMENTS FOR CHARACTERIZATION OF THE M.A.N. D2566 FMUH METHANOL TEST ENGINE

Exhaust Constituents(s) Measured or Characterized		Test Sequences							
		Transients				13-Mode		Seven (7) Extended Modes	(Full) Power Curve
		Cold		Hot					
		1	2	1	2	1	2		
Visible Smoke, PHS						✓			✓
Regulated Gaseous Emissions		✓	✓	✓	✓	✓	✓	✓	
Unburned Methanol		✓	✓	✓	✓			✓	
Individual Hydrocarbons		✓		✓				✓	
Aldehydes		✓	✓	✓	✓			✓	
Phenols		✓		✓					
Odor Index, DOAS		✓		✓				✓	
Particulate Characterization									
Mass		✓	✓	✓	✓			✓	
Size Distribution[e]		✓		✓					
C, H, N		✓		✓				✓	
Metal Content		✓		✓					
Characterization of Solubles in Particulate	Relative Priority[a]								
Mass	1	✓	✓	✓	✓			✓	
Boiling Range	4	✓		✓				✓	
BaP	2	✓		✓				✓	
Ames Bioassay[b,c]	3	✓	✓	✓	✓			✓	
HPLC Fractionation[d]	5	✓		✓					
C, H, N	6	✓		✓					

[a] relative importance assuming low extractables

[b] composite sample for transients to be tested in replicate over 5 strains

[c] individual samples from steady-state to be tested in replicate over 1 strain

[d] limited to quantitative determinations of aromatic, transitional and oxygenated fractions

[e] composite sample for transient particle sizing if particulate levels are low

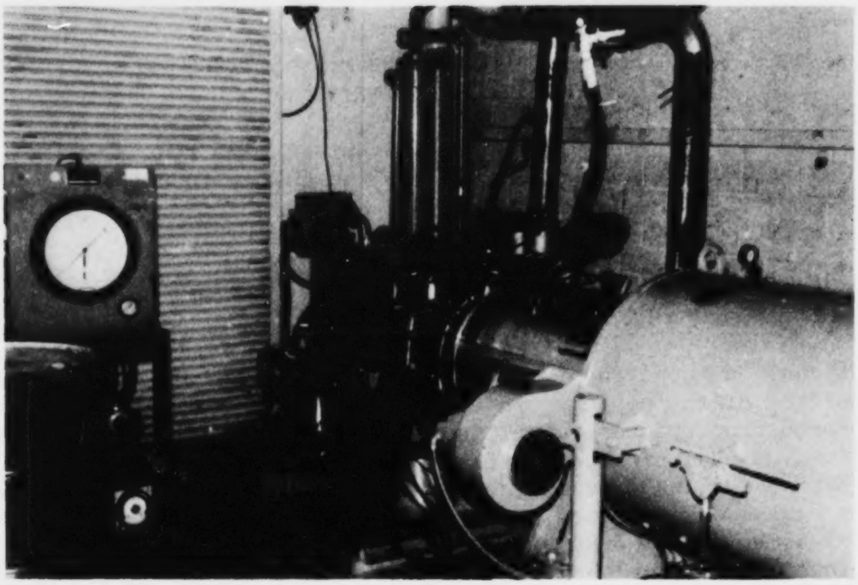

Figure 1. M.A.N. D2566 FMUH methanol engine mounted for testing

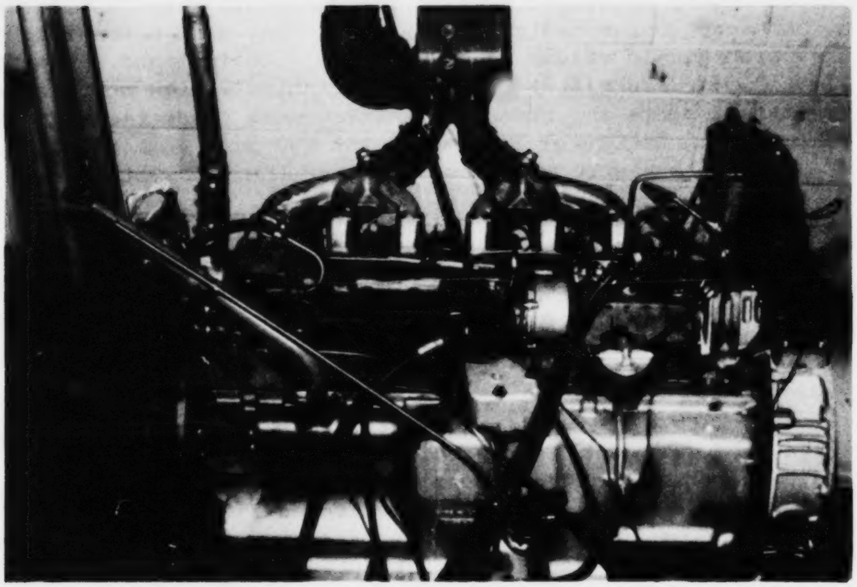

Figure 2. Left-side view of M.A.N. D2566 FMUH methanol engine

TABLE 3. SPECIFICATIONS FOR THE M.A.N. D2566 FMUH METHANOL ENGINE

Maximum Output	147 kW (198 hp) at 2200 rpm
Maximum Torque	836 N•m (627 ft-lb) at 1000 rpm
No. Cylinders	6
Bore	125 mm (4.921 inches)
Stroke	155 mm (6.102 inches)
Displacement	11.4 liters
Compression Ratio	18:1

The methanol is injected directly into a bowl-shaped combustion chamber formed in the top of the piston. Injecting the methanol directly into this "M system" combustion chamber, as illustrated in Figure 4, takes advantage of methanol's high heat of vaporization by reducing thermal stressing and recovering heat otherwise lost to the wall.(1) The spark-ignition system used on this engine was composed of a Bosch transistorized ignition control module, distributor with inductive pick-up, ignition coil and spark plugs. The spark plugs were custom designed for this engine (Bosch No. A 241 000 252) having extended electrodes as shown in Figure 3.

The engine tested in this program had a methanol injection timing of 31 degrees BTDC (static) with a spark ignition timing of 16 degrees BTDC.(3) The test engine was equipped with an exhaust catalyst as shown in Figure 4. Two catalyst assemblies were used in parallel, each handling exhaust from a separate manifold fed by three cylinders. The catalysts were manufacturered by Engelhard, and were designated as type PTX-D. They used a Corning 8M 20/400 type substrate, with a unit volume of 1.90 liters (116 in^3) and a platinum loading of 2.75 g/liter (78 g/ft^3) which is a relatively high noble metal content. Both steady-state and transient testing were conducted with engine intake and exhaust restrictions of 300 mm (12 in) H_2O and 74 mm (2.9 in) Hg, respectively. The backpressure was measured after the catalyst.(3)

C. Description of Test Fuel and Lubricating Oil

The engine was operated on neat methanol. Methanol was obtained commercially in drums, and was at least 99.9 percent pure. For comparative purposes, Table 4 lists some of the properties of both diesel fuel and methanol.

Lubrication problems are often encountered when operating any reciprocating engine on neat methanol. Some specifications of the lubricating oil supplied by M.A.N. for this program are given in Table 5. In addition, a portion of the used engine oil was submitted to analysis for comparison of properties to those of the soluble organic fraction (SOF) obtained from the total particulate. Those results will be presented in the Results section dealing with elemental composition of the particulate (page 46).

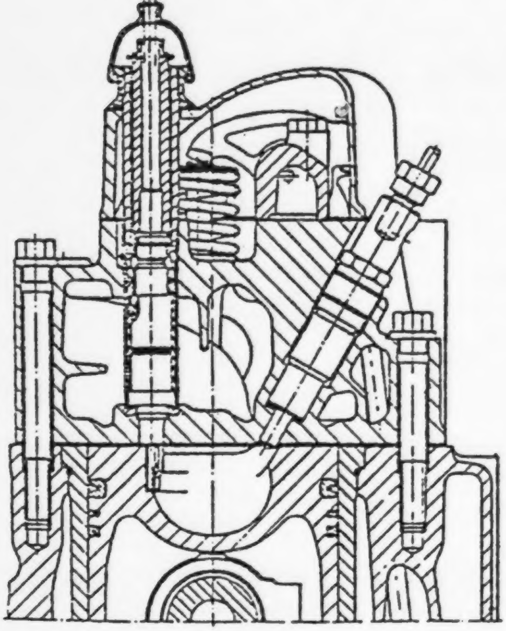

Figure 3. Combustion chamber configuration of the M.A.N. D2566 FMUH methanol engine

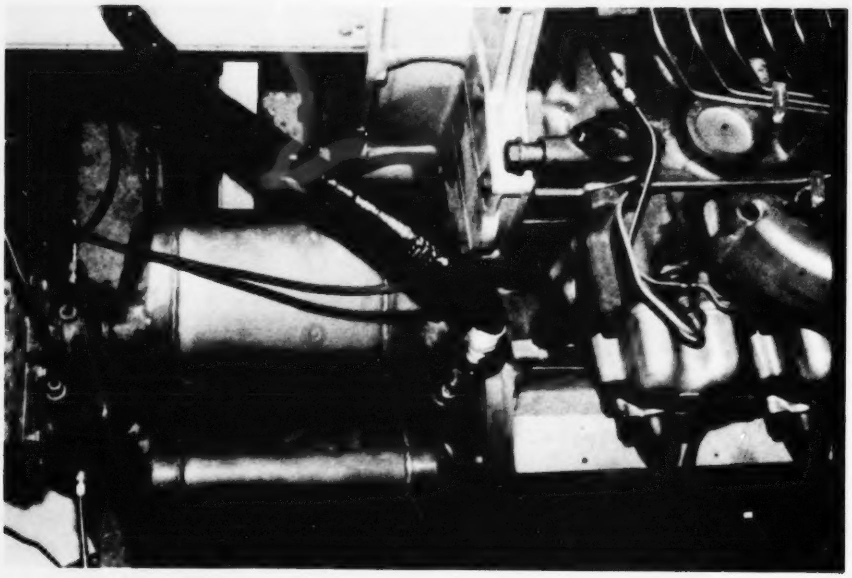

Figure 4. Catalyst assembly used on a M.A.N. spark-ignited engine (with heated sample probe for emission measurement before the catalyst)

TABLE 4. PROPERTIES OF DIESEL AND METHANOL FUELS(2)

Property	Units	Diesel	Methanol
Liquid Density	kg/m^3	852	796
Boiling Point(s)	°C	168-342	65
Flash Point	°C	58	11
Lower Heating Value	MJ/kg	42.8	19.7
	MJ/dm^3	36.5	15.7
Heat of Vaporization	KJ/kg	300	1100.
Stoichiometric A/F Ratio		14.6	6.4
Cetane Number		45	3
H/C Mole Ratio		1.66-1.85	4.00
O/C Mole Ratio		0	1.00
Percent Fuel Carbon		86-88	37.5

TABLE 5. PROPERTIES OF LUBRICATIING OIL SUPPLIED FOR THE M.A.N. D2566 FMUH METHANOL ENGINE(3)

Manufacturer	Deutsch BP AG
Trade Name	Special K7 for Methanol Engine
S.A.E. Viscosity Number	15 W-40
Viscosity Index	156
Pour Point	-33°C
Carbon Residue	1.25 PCT WT
Density at 15°C	0.888
Flash Point	230°C
Special Additives	None
Total Base Number	9.0
Type of Base	Middle East Solvent Refined

D. Test Procedures

Emissions from the M.A.N. D2566 FMUH methanol engine were measured during both steady-state and transient engine exercises. Steady-state operation and measurement techniques were based on the 1979 13-mode Federal Test Procedure (FTP).(5) Transient operation and measurement techniques were based on the 1984 FTP and 1986 Proposed Heavy-Duty FTP, which includes particulate sampling and analysis.(6,7)

The 13-mode test procedure is an engine exercise which consists of 13 individual modes of steady-state operation. Starting with a fully warmed engine, the first mode is an idle condition. This idle is then followed by 2, 25, 50, 75 and 100 percent load at intermediate speed followed by another idle mode, then to rated speed - 100, 75, 50, 25, and 2 percent of full load, followed by a final idle mode. Intake air, fuel, and power output are monitored along with other data to be used in calculating modal emission rates. A 13-mode composite emission rate is calculated on the basis of modal weighting factors as specified in the Federal Register.(5)

Unregulated emissions were measured over 7 modes of steady-state operations instead of 13 modes. This 7-mode procedure is a variation of the 13-mode procedure and consists of only the 2, 50 and 100 percent loads at intermediate and rated speeds, plus one idle condition.

On the basis of the 13-mode FTP weighting factors, 7-mode composite emissions were computed using weighted factors shown in Table 6. As the number of modes decreases, each modal point represents more time in mode and a wider range of power; thus the weighting for each of the 7 modes must be increased compared to its factor for 13-mode use. For both the 13-mode and the 7-mode procedures, the idle condition accounts for 20 percent of the composite value (equivalent to 20 percent of operating time).(8)

TABLE 6. LISTING OF 13-MODE AND 7-MODE WEIGHTING FACTORS

13-Mode			7-Mode	
Mode	Engine Speed/Load, %	Wt. Factor	Mode	Wt. Factor
1	Idle	0.067		
2	Intermediate/2	0.080	1	0.12
3	Intermediate/25	0.080		
4	Intermediate/50	0.080	2	0.16
5	Intermediate/75	0.080		
6	Intermediate/100	0.080	3	0.12
7	Idle	0.067	4	0.20
8	Rated/100	0.080	5	0.12
9	Rated/75	0.080		
10	Rated/50	0.080	6	0.16
11	Rated/25	0.080		
12	Rated/2	0.080	7	0.12
13	Idle	0.067		
	Composite	1.000	Composite	1.00

Transient engine operation was performed in accordance with the 1984 Transient FTP for Heavy-Duty Diesel Engines.(6) The procedure specifies a transient engine exercise of variable speed and load, depending on the power output capabilities of the test engine. The cycle requires relatively rapid dynamometer control, capable of loading the engine one moment and motoring it the next. The system used in this program consisted of a GE 200 hp motoring/250 hp absorbing dynamometer coupled to a Midwest 500 hp eddy current (absorbing) dynamometer, with a suitable control system fabricated in-house.

The 1984 Transient cycle is described in the Federal Register by means of percent torque and percent rated speed for each one-second interval, over a test cycle of 1199 seconds duration. The 20-minute transient cycle, developed from heavy-duty truck data, is composed of four five-minute segments. The four segments are described below:

Transient Cycle

Segment	Time, sec.
New York Non-Freeway (NYNF)	297
Los Angeles Non-Freeway (LANF)	300
Los Angeles Freeway (LAF)	305
New York Non-Freeway (NYNF)	297

In order to generate the transient cycle for the M.A.N. engine, the engine's full power curve was obtained from 400 rpm to maximum no load engine speed. Data from this "power curve", or engine map, was used in conjunction with the specified speed and load percentages to form the transient cycle.

As an example, a graphic presentation of speed and torque commands which constituted an FTP transient cycle for a 250 hp diesel engine is given in Figure 5. For this example, the resulting cycle work was 11.68 kW hr (15.66 hp hr) based on a peak torque of 880 N•m (650 ft lbs) and a rated speed of 2200 rpm. The relatively large negative torque commands shown in the figure are to insure that the "throttle", or rack control, goes closed for motoring operation.

The two NYNF segments, which are the initial and final cycle segments of the transient cycle, together contain approximately 23 percent of the total reference work called for by the transient cycle. The LANF segment contains 20 percent and the LAF contains 57 percent of the total transient cycle reference work. This comparison illustrates that most of the work is produced during the LAF cycle segment.

The transient cycle is perceived as a lightly-loaded duty cycle. The average duty factor over the entire transient cycle is approximately 20 percent of available engine power. The NYNF only calls for an average of 9 percent of the maximum power available from the engine; whereas the LANF calls for approximately 15 percent and the LAF requires about 45 percent. In addition, each NYNF segment contains 165 seconds of idle and 27 seconds of motoring, the LANF segment contains 98 seconds of idle and 79 seconds of motoring, and the LAF segment contains 11 seconds of idle and 45 seconds of motoring.

Of the 1199 seconds of the transient cycle, closed rack commands account for 617 seconds. Therefore, the engine must attempt to produce the reference cycle work within the remaining 582 seconds. These statistics mean that the engine has to produce an equivalent of 40 percent of its maximum power for the remaining "non-idle" time of the cycle (582 seconds). These observations stress the relative importance of pollutant emissions during idle, accelerations and medium- to light-load conditions.

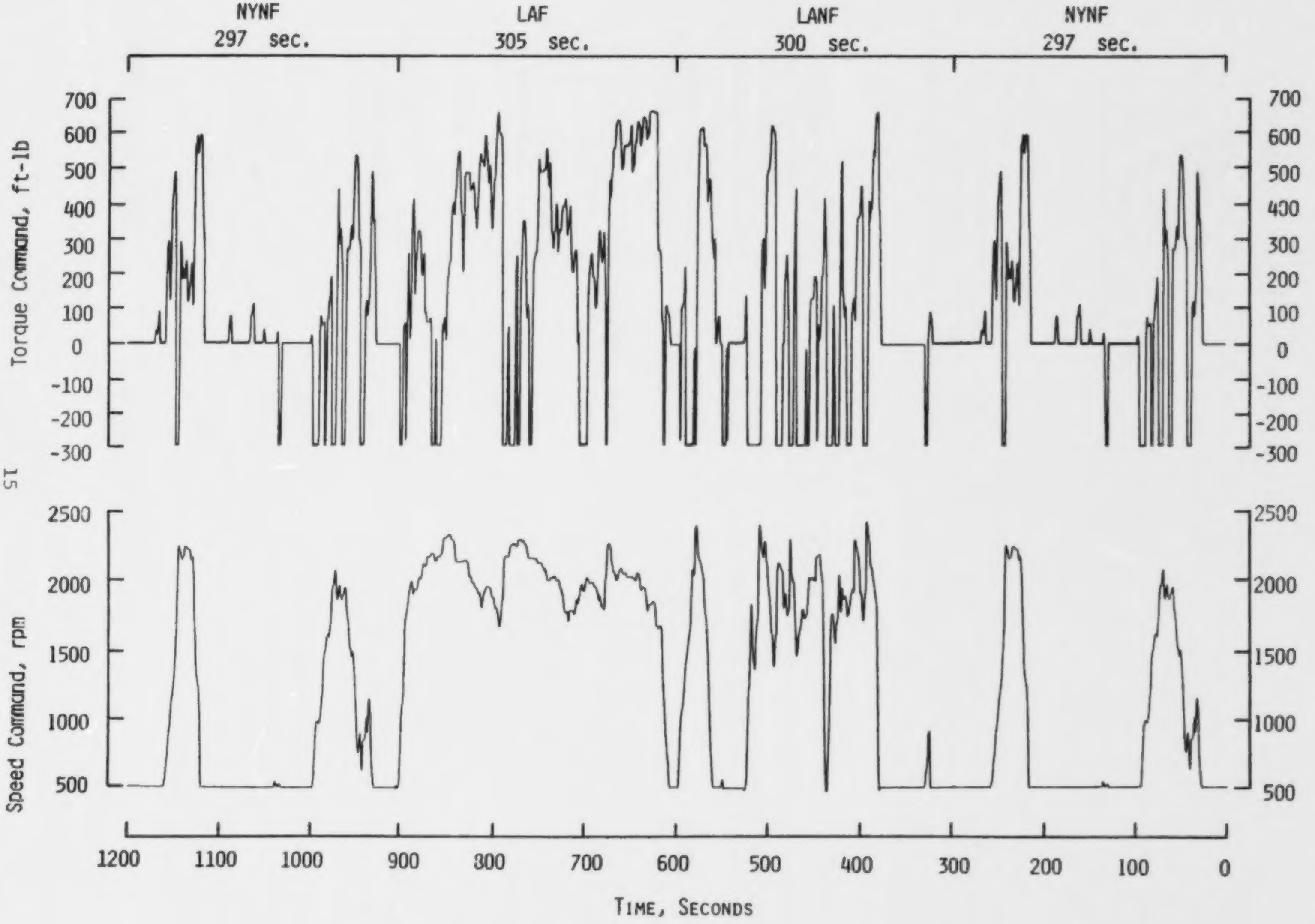

Figure 5. Graphic representation of torque and speed commands for the 1984 Transient FTP cycle for a 250 hp at 2200 rpm diesel engine

A Transient FTP Test consists of a cold-start transient cycle and a hot-start transient cycle. The same engine control or command cycle is used in both cases. For the cold-start, the engine was operated over a "prep" cycle, then allowed to stand overnight in an ambient soak temperature of 20 to 30°C (68 to 86°F). The cold-start transient cycle begins when the engine is cranked for cold start-up. Upon completion of the cold-start transient cycle, the engine is shut down and allowed to stand for 20 minutes. After this hot soak period, the hot-start cycle begins with engine cranking.

All engines react somewhat differently to the transient cycle commands, due to both cycle and engine characteristics. In order to judge how well the engine follows the transient cycle command, engine responses are compared to engine commands using least squares regression techniques and several statistics are computed. According to the Federal Register, the following regression line tolerances should be met.

REGRESSION LINE TOLERANCES

	Speed	Torque	Brake Horsepower
Standard Error of Estimate (SE) of Y on X	100 rpm	13% of Maximum Engine Torque	8% of Maximum Brake Horsepower
Slope of the Regression Line, M	0.970 1.030	0.83-1.02 Hot 0.77-1.02 Cold	0.89-1.03 (Hot) 0.87-1.03 (Cold)
Coefficient of Determinations, R^2	0.9700 1/	0.8800 (Hot) 1/ 0.8500 (Cold) 1/	0.9100 1/
Y Intercept of the Regression Line, B	±50 rpm	±15 ft lbs	±5.0 of brake horsepower

1/ Minimum

In addition to these statistical parameters, the actual cycle work produced should not be more than 5 percent above, or 15 percent below, the work requested by the command cycle.

If the statistical criteria are not met, then adjustments to throttle servo linkage, torque span points, speed span points, and gain to and from error feedback circuits can be made in order to modify both the engine output and the dynamometer loading/motoring characteristics. After completion of the cold-start and the hot-start transient cycles, transient composite emissions results are computed by the following:

$$\text{Brake Specific Emissions} = \frac{1/7\ (\text{Mass Emissions, Cold}) + 6/7\ (\text{Mass Emissions, Hot})}{1/7\ (\text{Cycle Work, Cold}) + 6/7\ (\text{Cycle Work, Hot})}$$

The engine was also operated over the 1979 Smoke FTP exercise. It essentially consists of a 5-minute idle followed by two full throttle accelerations to rated speed, and finally, a full throttle lug-down from rated speed. This transient smoke test cycle was run only for the measurement of visible smoke emissions.

E. Analytical Procedures

The analytical systems used for each category of emission measurements are described in this section. The section is divided into two parts, the first dealing with gaseous emissions characterization and the second with total particulate emissions and the constituents of the total particulate. Gaseous emissions included HC, CO, CO_2, NO_x, and some unregulated pollutants. Unregulated gaseous emissions included individual hydrocarbons, aldehydes, phenols, unburned methanol, and odor. Particulate emissions included determination of the total particulate mass, and its content of metals, carbon and hydrogen. The size distribution of the particles was determined, as well as the fraction soluble in methylene chloride. This soluble fraction was characterized for BaP content, bioactivity by the Ames test, boiling point distribution, fractionation (by relative molecular polarity), and for carbon, hydrogen and nitrogen content.

During steady-state or modal engine exercises, regulated and some unregulated gaseous emissions can be sampled from the raw exhaust stream since a representative and proportional sample can be obtained. Obtaining proportional samples during transient engine operation requires the use of a constant volume sampler (CVS).(6,7) All transient cycle test work run for regulated emissions of HC, CO, NO_x as well as particulate was conducted with a main tunnel flow of 1000 SCFM, which provided approximately a 4:1 cycle dilution ratio of the total exhaust introduced. Unregulated gaseous emissions of aldehydes, individual hydrocarbons, phenols, and odor were sampled from the primary tunnel during the transient testing. During these runs for regulated emissions, particulate mass emissions were determined by use of a small secondary dilution tunnel. This small secondary tunnel, shown in Figure 6, is attached to the primary tunnel and diluted the primary dilute exhaust further to an overall ratio of about 12:1. The small secondary dilution tunnel was operated at approximately 4 SCFM total flow in order to collect particulate on two 90 mm T60A20 Pallflex filters, in series. Weight gains from these two filters are used to determine the filter efficiency. If the filter efficiency is greater than or equal to 95 percent then only the weight gain from the first filter is used, whereas if the filter efficiency is less than 95 percent, then weight gains from both filters are used to determine the total particulate mass emission from the engine.

In order to obtain large particulate samples and for particle sizing during transient operation, the primary tunnel was operated as a single-dilution CVS. To obtain approximately a 12:1 dilution ratio, the CVS flow was increased to about 4000 SCFM during the transient cycle which permitted collection of large quantities of particulate on 20x20 inch filters.

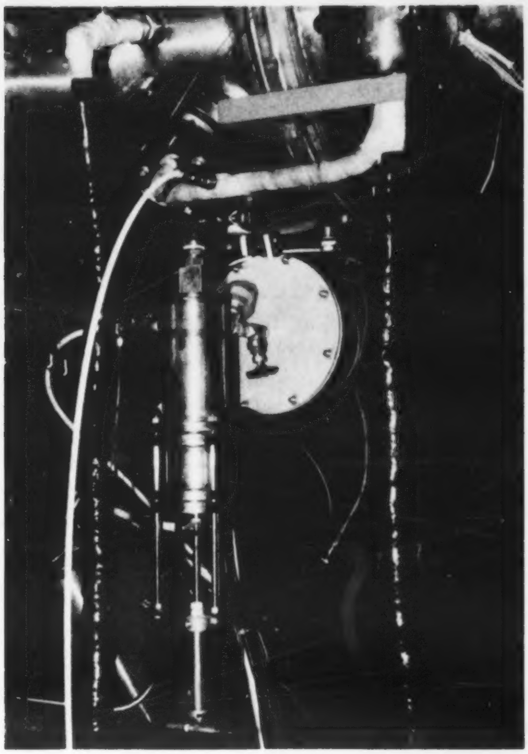

Figure 6. Secondary dilution tunnel for particulate mass rate by 90 mm filters

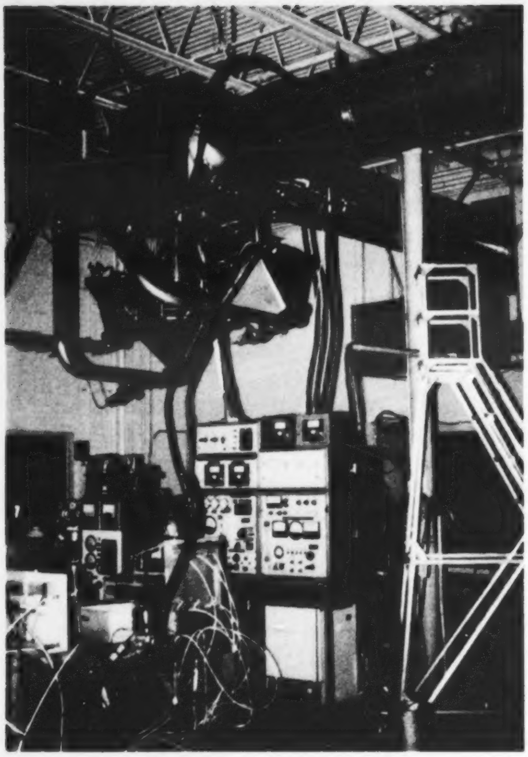

Figure 7. Filter holders for large particulate sample acquisition

Large filter holders and the associated tunnel are shown in Figure 7. This same CVS system was used to collect particulate samples from steady-state operation of the engine, by altering the main dilution tunnel flow to accommodate the total exhaust from the engine without exceeding 52°C (125°F) at the particulate filter face.

Prior to particulate emission sampling, the dilution tunnel, sample probes, and filter holders were cleaned to insure against potential interference from background particulate.

1. Gaseous Emissions

Regulated gaseous emissions of HC, CO, and NO_x were measured according to the 1979 13-mode FTP and the 1984 transient FTP. The regulated emissions along with CO_2 were determined from raw exhaust samples taken during the 13-mode steady-state procedure. These same four constituents were determined in dilute exhaust samples taken during the transient procedure. The transient procedure requires that HC be determined from integration of continuous concentration monitoring of the CVS dilute exhaust. The procedure provides the option of determining CO, CO_2 and NO_x from either dilute sample bags or from integration of continuous concentration monitoring.

Hydrocarbons were measured over both test procedures using the specified heated sample train (190°C). During steady-state operation, raw exhaust sample was transferred to a Beckman 402 heated flame ionization detector (HFID) by heated Teflon sample line. During transient operation, CVS-diluted exhaust was taken from the main dilution tunnel using the prescribed heated probe and heated filter, and was transferred to the 402 HFID by heated stainless steel sample line.(6) The intent of both procedures is to determine the "total" HC emissions from the engine under test. It is generally assumed that the exhaust hydrocarbons emitted from a diesel engine are of the same general composition as the diesel fuel. The total is usually based on the indication from HFID instruments, but the FID response to various species of alcohols, individual hydrocarbons, aldehydes, and phenols often differs from the response to diesel fuel-like constituents.(9) Special consideration of "total hydrocarbons" will be expressed in the discussion of the Results section.

Carbon monoxide was measured during both engine test procedures using non-dispersive infrared (NDIR) instruments. Emissions of CO_2 were also determined by NDIR for use in fuel consumption calculations by carbon balance. Both CO and CO_2 were determined from raw exhaust samples transferred by heated Teflon sample lines during the 13-mode procedure. During transient test procedures, CO and CO_2 levels were determined from proportional dilute exhaust bag samples.

NO_x emissions were determined by chemiluminescence (CL) from raw exhaust during steady-state operation, and from both dilute sample bags and integration of continuous NO_x concentration monitoring during transient operation. The transient NO_x level determined from the bag sample has generally been lower (5-15 percent) than that indicated by continuous NO_x measurement techniques.(10) No NO_x correction factor for intake humidity was applied for either steady-state or transient testing, due to the uncertain validity of the factor when oxygen-containing fuels are consumed. In the case of the transient test operation, the engine intake humidity and temperature were controlled to 60-90 grains/lb of dry air and 68-86°F.

Unburned methanol quantities were also determined for both modal and transient operation. For unburned methanol, dilute or raw exhaust (depending on engine operation) was drawn through glass bubblers containing distilled water at 2°C in order to condense out and collect unburned methanol.(11) The level of methanol collected was determined by gas chromatograph using an FID specifically calibrated for quantitive purposes.

Some selected individual hydrocarbons (IHC) were determined from dilute exhaust bag samples taken over the cold-start and hot-start transient cycles using the CVS. Bag samples of raw exhaust were also taken over seven individual modes of steady-state operation. A portion of the exhaust sample collected in the Tedlar bag was injected into a four-column gas chromatograph using a single flame ionization detector and dual sampling valves. The timed sequence selection valves allowed the baseline separation of air, methane, ethane, ethylene, acetylene, propane, propylene, benzene, and toluene.(11)

Aldehydes and ketones were determined using the 2,4-dinitrophenylhydrazine (DNPH) method.(11) Raw exhaust samples were taken during steady-state operation; whereas dilute samples were taken from the main CVS dilution tunnel during transient testing. In both cases a heated Teflon sample line and filter were maintained at 190°C (375°F). The procedure consists of bubbling filtered exhaust gases, dilute or raw, through glass impinger traps containing a solution of DNPH and HCl kept near 0°C. The aldehydes form their respective phenylhydrazone derivatives (precipitates). These derivatives are removed by filtration and were subsequently extracted with pentane and evaporated in a vacuum oven. The remaining dried extract, which contains the phenylhydrazone derivatives, is dissolved in a specific volume of toluene with anthracene internal standard. A portion of this dissolved extract is injected into a gas chromatograph and analyzed using a flame ionization detector to separate formaldehyde, acetaldehyde, acetone, isobutyraldehyde, methylethylketone, crotonaldehyde, hexanaldehyde, and benzaldehyde.

Phenols, which are hydroxyl derivatives of aromatic hydrocarbons, were measured using an ether extraction procedure detailed in Reference 8. Dilute samples were taken from the main CVS dilution tunnel during transient operation only. Dilute exhaust samples were filtered and collected in impingers containing aqueous potassium hydroxide. The contents of the impingers were acidified with sulfuric acid, then extracted with ethyl ether. This extract was injected into a gas chromatograph equipped with an FID in order to separate 11 different phenols ranging in molecular weight from 94.11 to 150.22.

Total intensity of aroma (TIA) was quantified by using the Coordinating Research Council Diesel Odor Analytical System (DOAS). Dilute or raw sample, depending on engine operation, was drawn off through a heated sample train and into a trap containing Chromosorb 102. The trap was later eluted and injected by syringe into the DOAS instrument, which is a liquid chormatograph that separates an oxygenate fraction (liquid column oxygenates, LCO) and an aromatic fraction (liquid column aromatics LCA). The TIA values are defined as:

$$\text{TIA} = 1 + \log_{10} (\text{LCO}, \mu g/\ell)$$

or

$$\text{TIA} = 0.4 + 0.7 \log_{10} (\text{LCA}, \mu g/\ell) \quad \text{(TIA by LCO preferred)}$$

A.D. Little, the developer of the DOAS instrument, has related this fraction to TIA sensory measurement by the A.D. Little odor panel.(12) The system was intended for raw exhaust samples from steady-state operating conditions, but for this program, dilute samples of exhaust were taken in order to determine a TIA value for transient operation. Where dilute samples were taken, the resulting values were increased in proportion to the dilution ratio.

2. Particulate Emissions

Particulate emissions were determined from dilute exhaust samples utilizing various collection media and apparatus, depending on the analysis to be performed. Particulate has been defined as any material collected on a fluorocarbon-coated glass fiber filter at or below a temperature of 51.7°C (125°F), excluding condensed water.(7) The 125°F temperature limit and the absence of condensed water dictates that the raw exhaust be diluted, irrespective of engine operating mode. The temperature limit generally required dilution ratios of approximately 12:1 (total mixture:raw exhaust).

Total particulate-rate samples were collected on 90 mm Pallflex T60A20 fluorocarbon-coated glass fiber filter media by means of a double-dilution technique for transient operation and a single-dilution technique for steady-state operation. Gravimetric weight gain, representing collected particulate, was determined to the nearest microgram after the filter temperature and humidity were stabilized. This weight gain, along with CVS flow parameters and engine data, were used to calculate the total particulate mass emission of the engine under test.

Smoke and total particulate are related in that the relative level of smoke opacity indicates the relative level of particulate. The absence of smoke, however, does not indicate the absence of particulate. Smoke was determined by the end-of-stack EPA-PHS smokemeter, which monitored the opacity of the raw exhaust plume as it issued from the 3 inch diameter exhaust pipe. Smoke opacity was determined for 13-mode operation, power curve operation, and for the smoke FTP.(5)

Since total particulate, by definition, includes anything collected on fluorocarbon-coated glass fiber filter media, there has always been an interest in finding out what constitutes the "total particulate." The following paragraphs describe the methods and analysis used to determine some of the properties of the total particulate.

A particle size distribution of particulate generated over the transient cycle was determined using a Sierra Series 220 cascade inertial impactor. Dilute exhaust particles having a variety of shapes and densities were fractionated and collected according to their aerodynamic characteristics. The aerodynamic size gives information relating to the physical size, shape, and density of the particulate, indicating how the particles may behave in the environment. Pre-weighed stainless steel impactor discs were used for stage collection, and a pre-weighed fluorocarbon-coated glass fiber filter was used as a back-up filter to collect all particulate aerodynamically smaller than the lowest stage cut-off size (0.06 microns Effective Cut-Off Diameter, or ECD). Impactor flow rate was selected to provide individual stage separation from 6.5 to 0.06 microns ECD.

Carbon, hydrogen, metals, and other elements that make up the total particulate are also of interest. A sample of "total particulate" was collected on 47 mm Type A (Gelman) glass fiber filter media for the purpose of determining the carbon and hydrogen weight percentages. This analysis was performed by Galbraith Laboratories using a Perkin-Elmer Model 240B automated thermal conductivity CHN analyzer. A sample of total particulate matter was also collected on a 47 mm Fluoropore filter for the determination of trace elements such as calcium, aluminum, phosphorus, and sulfur by x-ray fluorescence. This analysis was conducted at the EPA, ORD laboratories in Research Triangle Park, N.C. using a Siemens NRS-3 X-ray fluorescence spectrometer.

Diesel particulate generally contains significant quantities of condensed fuel-like or oil-like hydrocarbon aerosols generated during incomplete combustion. In order to determine to what extent total particulate contains these various hydrocarbons, large particulate-laden filters (20x20 inch) were washed with an organic solvent, methylene chloride, using 500 mℓ soxhlet extraction apparatus. The dissolved portion of the "total particulate" carried off with the methylene chloride solvent has been referred to as the "soluble organic fraction" (SOF). All filter handling, extraction processes, and handling of concentrated SOF were carried out according to EPA recommended protocol.(13) The SOF may be composed of anything carried over the extraction process, so its composition is also of interest. Generally the SOF contains numerous organic compounds, many of which are difficult to isolate and quantify. SOF from diesel particulate has almost always been shown to be mutagenic using the Ames test.

Benzo(a)pyrene (BaP) is considered to be a very general indicator of the relative poly-nuclear aromatics (PNA) content of the SOF. The analytical method used for the determination of BaP is described in Reference 14. The procedure is based on high-performance liquid chromatography to separate BaP from other organic solubles in particulate matter, and it incorporates fluorescence detection to measure BaP. The instrument used was a Perkin-Elmer 3B liquid chromatograph equipped with a MPF-44 fluorescence spectrophotometer. Excitation was at a wavelength of 383 nanometers, and emission was read at 430 nanometers.

Samples of SOF were submitted for Ames testing. The Ames test, as employed in this program, refers to a bacterial mutagenesis plate assay with Salmonella typhimurium according to the method of Ames.(15) This bioassay determines the ability of chemical compounds or mixtures to cause mutation of DNA in the bacteria, with positive results occurring when histidine-dependent strains of bacteria revert (or are mutated) genetically to forms which can synthesize histidine on their own. Samples of SOF were shipped under dry ice to an EPA contractor (Microbiological Associates, Inc.) for Ames test response determination.

The boiling range of the SOF was determined by SwRI's Mobile Energy Research Division using a high-temperature variation of ASTM-D2887-73. Approximately 50 mg of the SOF was dissolved in solvent and an internal standard (C_9 to C_{11} compounds) was added. This sample was then submitted for instrumental analysis of boiling point distribution. In some cases, insufficient sample was available to use internal standards.

Another portion of the SOF sample was submitted for fractional separation. The method involves separation of the extractables into a series of fractions of increasing polarity. A high performance liquid chromatographic procedure which utilizes a variable solvent program was used to elute increasingly polar compounds. BaP, 9-fluorenone and acridine standards are injected to indicate the types of compounds eluted in each region of the chromatogram.(16)

Carbon, hydrogen and nitrogen were determined for the SOF. Relative elemental content of the "dried" extract was determined by Galbraith Laboratories using a Perkin-Elmer Model 240B automated thermal conductivity CHN analyzer.

IV. RESULTS

This section describes the results obtained from numerous emission measurments and sample analyses conducted on the M.A.N. D2566 FMUH Methanol Engine tested with an oxidation catalyst. It is divided into three parts. The first part describes some of the pertinent details and the chronology of the accumulated test results. The next two parts detail the accumulated gaseous and particulate data, respectively. Overall emission trends and general remarks are given along with the results.

A. General Test Notes

The M.A.N. D2566 FMUH methanol engine arrived in good condition on December 8, 1981. The shipment included necessary ignition system components, auxiliary fuel delivery pumps, special engine oil, and an oxidation catalyst assembly as well as reference drawings for engine installation. Although actual engine mounting was delayed due to an ongoing project, the ignition system was installed. Contact was made with Mr. F. Chmela of M.A.N. in Nurnberg, Germany via telex concerning questions of fuel system set-up. Calibrations of the Flowtron, laminar flow element (LFE), and the emissions instrumentation were verified. The engine was installed in our transient-capable test facility, cell 4, and engine operation was begun January 8, 1982.

The engine operated well until the 2200 rpm/50 percent load was reached. Beyond this loading the engine began to misfire. At first the problem was thought to be related to the fuel supply, but it was discovered that a relay mounted on an engine mounted bracket to provide remote ON/OFF ignition had failed due to eroded contacts. The relay was replaced and engine operational checkouts were continued. The engine developed 147 kW (198 hp) at 2200 rpm with a methanol flow of 77.1 kg/hr. The fuel temperature was approximately 10°C (50°F).

Steps were taken to warm the methanol, which had a relatively low boiling point (65°C or 149°F), to about 27°C (80°F) . With a fuel temperature of 22°C (72°F), a maximum power of 141 kW (189 hp) was obtained with a fuel flow of 75.7 kg/hr (166.8 lb/hr) of fuel. The engine began to misfire again and the ignition relay showed signs of contact failure, thought to be caused by the engine vibration. The ignition relay was replaced again, but this time the relay was isolated from the engine. An initial 13-mode emissions test was run and no problems with the engine were encountered. The catalyst exit temperature was monitored, and it ranged from 520°F during mode 13 (idle) to 999°F during mode 6 (full load/ intermediate speed).

Preparation for a transient map of engine speed and torque were made. The engine operated well during the warm-up for the map procedure. With

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the map program, the engine was automatically lugged down to 400 rpm, the rack was moved to full load condition and the speed was allowed to increase by about 8 rpm/sec. When the engine speed approached the rated speed of 2200 rpm the torque dropped immediately, and it was thought that the overspeed governor had engaged prematurely. The catalyst temperature went from about 516°C (960°F) to 899°C (1650°F) in a matter of seconds. This temperature decreased slowly to about 316°C (600°F) while the engine was operating at idle speed. It was discovered at that point that the engine was actually being motored. The engine was stopped immediately. Diagnostics showed that the ignition had failed during the mapping procedure. The ignition problem was traced to a failed transistorized ignition control module. Mr. Chmela was contacted, and arrangements were made for shipment of replacement parts including another catalyst.

It was thought that the catalyst might have survived the high temperature excursion. The catalyst assembly was removed and a visial inspection was made. No problem was noted, and the catalyst substrate appeared to be intact. Following a 5-day delay, the spare parts arrived and the transistorized control module was replaced. The engine operated satisfactorily and emissions from 1600 rpm/50 percent load and 2200 rpm/100 percent load were checked and showed emission levels of HC, CO, and NO_x similar to those detected during the initial 13-mode emission test. On the basis of the repeat emissions test points and catalyst exhaust temperature, the catalyst was assumed to be satisfactory, and testing was continued as planned. A transient power map was conducted and further test work was scheduled.

Following the completion of smoke testing, raw exhaust samples were taken to measure aldehydes, DOAS, unburned methanol and specific hydrocarbons over 7 modes of the 13-mode procedure. The coloration of the aldehyde bubblers indicated high concentrations of aldehydes from both the idle and the 2 percent conditions. Another 13-mode test was conducted to serve as a repeat test of the initial 13-mode. The catalyst temperature kept falling to about 200°C (390°F) while CO and HC continued to increase. This situation was even worse for mode 2, where catalyst temperature fell to 193°C (380°F). Although the 13-mode test was completed, it was apparent that the catalyst was no longer as effective as during the initial 13-mode test, and would have to be replaced.

The back-up catalyst was installed and the engine was operated at various power levels for about two hours. According to Mr. Chmela, no catalyst break-in period was needed, so another 13-mode test was conducted with the replacement catalyst. Catalyst exhaust temperatures and emissions were stable during all 13 modes of operation. Emission results from this test indicated lower HC and CO but significantly higher NO_x than initial 13-mode test results. This test was later voided due to low voltage supplied to the ignition module and another 13-mode test was planned prior to engine removal.

Since catalyst replacement was necessary, processing of steady-state samples for aldehydes, specific hydrocarbons, unburned methanol and DOAS was stopped and the samples stored. The collection of these unregulated emission samples was rescheduled, and emphasis was placed on obtaining particulate samples over the various operating conditions.

The CVS flow rates were adjusted and arrangements were made to obtain large particulate samples on 20x20 inch Pallflex filter media. From a preliminary look at particulate loadings obtained during 1 hour of engine operation at a 1600 rpm/50 percent load condition, it was decided that each of the seven steady-state modes would be run 2 hours for filter collection. Even after 2 hours of sampling, it was difficult to tell visually if a given filter had been used.

During a run of 2200 rpm/2 percent load steady-state operation for particulate, the engine began to misfire after about one and a half hours. The engine was shut down immediately to protect the catalyst. Upon initial inspection, it appeared that the distributor cap had developed hairline cracks between two of the towers. A new cap did not correct the problem. An inductive timing light indicated that a pluse was getting to each spark plug. It was assumed that the signal triggering the timing light was insufficient to cause a spark to jump the gap. A new coil corrected the problem, and the engine developed full power with no further difficulty.

The CVS flow was adjusted to 4000 cfm for a 12:1 dilution ratio, and other preparations were made for large particulate sample collection over the transient cycle. Particulate emissions were extremely low. A total of 2 cold-starts and 12 hot-starts were run to obtain adequate samples of total particulate for most analysis. These transient tests were labeled T-1 through T-14. Particulates from multiple test runs were collected on various filter media in order to acquire a higher particulate load-to-filter area ratio than obtained over a single transient cycle. Particle sizing by impactor utilized consecutive runs of 1 cold-start and 6 hot-start transient cycles (T-2 through T-8). The engine false-started during the cold-start, so the dynamometer was energized in order to keep the engine running. Normal transient test cold-start procedure involved cranking the engine, with the rack closed, until the engine operated on its own; then the engine is allowed to idle for the first 23 seconds prior to energizing the motoring/absorbing dynamometer. No rack movement is made during this "free idle period". In order to guard against false start-up, cold start-ups were conducted by energizing the dynamometer.

Following completion of transient testing for particulate, the engine began to misfire during warm-up operation the next day. A SUN ignition analyzer indicated that every other spark pulse was weak and noisy and that the wave form was shorter than normal. The distributor cap and magnetic pick-up were inspected. No fault was noted from a visual inspection of the overall ignition system. The engine was restarted and operated well; apparently the problem had disappeared.

To characterize gaseous emissions and particulate according to the proposed 1986 Transient FTP using the double dilution method, the CVS flow was reduced to 1000 cfm. Both regulated and unregulated gaseous emissions were sampled from the primary dilution tunnel, and particulate emissions were determined from the 90 mm double dilution system. Three Transient FTP sequences were performed, and they include transient tests labeled T-15 through T-20.

The engine was operated over 7 modes of steady-state operation in order to collect exhaust samples for aldehydes, IHC, DOAS and unburned methanol. Another 13-mode emission test was conducted. In addition to the normal sample probe after the catalyst, another sample probe was installed in front of the catalyst. Gaseous emissions of HC, CO, CO_2 and NO_x were sampled before and after the catalyst. During the final 13-mode test, the engine developed an intermittent misfire during the second test segment run at 2200 rpm. The misfire was occasional at the higher loads, but seemed to increase in frequency at lower loads. The 13-mode test was completed and the engine was shut down. After verifying that sufficient samples had been obtained, the engine was removed from the test facility and returned to M.A.N. of West Germany.

Upon inspection of the test engine and the associated ignition hardware, M.A.N. reported that the probable cause for the repeated ignition problems were due to heat build-up in the ignition control module and the ignition coil. These components were mounted relatively close to the test engine due to the length of pre-wired connectors supplied by M.A.N. and because no provisions or other recommendations for mounting were given. It is surmised that damage or intermittent functioning of the ignition components was due to the inability of the components to dissipate heat. M.A.N. has reported that the ignition control module may generate 2 to 3 times more heat in this application than in an automotive application and that for this reason, the module has been located in the intake air stream on prototype installations to insure good heat dissipation. Copies of correspondence between M.A.N. and EPA are given in Appendix C.

B. Gaseous Emissions

The term "gaseous emissions" usually refers to HC, CO, and NO_x, which are currently regulated emissions. This section presents the results of emission measurements which include not only these regulated gaseous emissions, but also selected individual hydrocarbons, unburned methanol, aldehydes, and phenols. These additional species are generally included in a qualitative way as part of the "total hydrocarbon." Odor intensity, which has been shown to correlate with the presence of these and other gas phase emissions, is also presented.

1. HC, CO, and NO_x

These regulated pollutants were measured over the 1979 FTP as well as the 1984 Transient FTP. In 1984, the transient test procedure will be optional in lieu of the 13-mode test procedure. In 1985, the transient test procedure will become mandatory, and 1986 the transient test procedure will include particulate measurement and regulation. For perspective, some of the proposed standards, beyond 1979, are listed in Table 7.

TABLE 7. HEAVY-DUTY DIESEL EMISSION STANDARDS, 1979-1986

Model Year	FTP	Regulated Emissions (g/hp-hr) HC	CO	NO_x	Particulate
1979	13-mode	1.5	25.	10.0	None[a]
	13-mode (opt.)	--	25.	5.0	None[a]
1984	13-mode[b]	0.5[c]	15.5[d]	9.0	None[a]
	Transient[b]	1.3	15.5[d]	10.7	None[a]
1985	Transient	1.3	15.5[d]	10.7	None[a]
1986	Transient	1.3	15.5[d]	4.0[e]	.25[e]

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[a] Federal Smoke Regulations apply

[b] Manufacturer may certify by either procedure

[c] Subject to revision to 1.0 g/hp-hr

[d] CO measurement requirements for Heavy-Duty diesels may be waived after 1983.

[e] Proposed (not finalized)

a. 13-Mode FTP

Thirteen mode emissions from the M.A.N. methanol engine were measured and computed on the basis of procedures and computational methods prescribed in the Federal Register for the 1979 13-mode FTP. Hydrocarbons were measured using the prescribed sample train, but CO, CO_2, and NO_x were measured using the specified sample train but with a dry ice and isopropyl alcohol (CO_2 ice-IPA) water trap. This type of water trap has a bath temperature of -76°C, and has been used by SwRI in the NO_x sample stream due to its superior water trapping performance over the typically used water-ice water trap with a bath temperature of about 2°C.(17) The CO_2-IPA water trap was also used in the CO and CO_2 sample trains in this program when it appeared that the water-ice water trap was insufficient to handle the increased water vapor formed by the combustion of methanol. Measured concentrations of CO, CO_2 and NO_x were increased by 0.7 percent of their corrected values to account for the additional water removal by the CO_2-IPA water trap over the conventional water-ice water trap.

Some modifications and assumptions were made in computing the 13-mode composite emissions to account for the consumption of oxygen-containing fuel. A hydrogen-to-carbon ratio of 4.0 and an oxygen-to-carbon ratio of 1.0 were used to process the 13-mode emissions. These two ratios were used in computing stoichiometric and actual f/a ratios, HC wet-to-dry correction, and NO$_x$ correction factors. Although the NO$_x$ correction factor for intake humidity was computed, it was not applied to any of the results due to the uncertainty regarding the applicability of the correction when oxygen-containing fuels are used. Hydrocarbon emission data from the methanol-fueled engine were computed using a molecular weight of 13.88 per carbon atom, similar to that used for engines using diesel fuel. The ratio of molecular weights of methanol to diesel fuel (on a per carbon atom basis) is 2.31. No correction for variable HFID response to unburned fuel-like constituents, like unburned methanol, was used.

Three valid 1979 13-mode Federal Test Procedures for gaseous emissions were conducted during this test program. The results from these three tests are given in Table 8 along with reference data provided by M.A.N.

TABLE 8. GASEOUS EMISSION SUMMARY FROM 13-MODE OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Test No.	Date	13-Mode Emissions, g/kW-hr, (g/hp-hr) HC	CO	NO$_x$[a]	BSFC kg/kW-hr (lb/hp-hr)	Comment
-	-	0.23[b] (0.17)	0.92[b,c] (0.69)	5.78[b] (4.31)	0.796[b] (1.309)	Manufacturer's
1	1/12/82	0.27 (0.20)	0.36 (0.27)	9.00 (6.72)	0.616 (1.014)	SwRI Initial Test
2	1/22/82	0.68 (0.51)	1.18 (0.88)	9.37 (6.99)	0.630 (1.036)	Partially Failed Catalyst
3	2/24/82	0.20 (0.15)	0.41 (0.31)	9.26 (6.91)	0.632 (1.039)	After 35 hrs. on New Catalyst
3	2/24/82	7.89[d] (5.89)	11.05[d] (8.24)	9.36[d] (6.98)	0.633[d] (1.041)	Measured Before Catalyst

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[a] No NO$_x$ correction factor for humidity was applied to SwRI results

[b] Mode 2 and mode 12 were run at 8.6 percent and 17.2 percent of power instead of 2 percent of load

[c] Appears that resolution of CO instrument was very coarse

[d] Emission measured in front of catalyst. These results were obtained during the engine operation for test 3

for the same engine. Copies of the corresponding computer printouts of the 13-mode test results are given in Appendix A, and provide emissions information along with measured methanol f/a and diesel equivalent f/a ratios on a modal basis. Since the engine incorporates an oxidation catalyst for exhaust aftertreatment, catalyst exhaust temperatures were monitored and are given in Table 9. The minimum light-off temperature for the catalyst was reported by M.A.N. to be approximately 200°C (392°F).

The first 13-mode test was conducted shortly after the engine installation was completed. Following completion of some test work, the second 13-mode test was performed with a malfunctioning or partially failed catalyst which did not allow the emissions to stabilize during the light load conditions. Emission concentrations from the second test were recorded after approximately 5 minutes in mode, which generally corresponds to catalyst temperatures given in Table 9. The partially failed catalyst was replaced, and following completion of most test work another 13-mode FTP (Test No. 3) was performed. Emissions levels before and after the catalyst were determined during the third 13-mode FTP.

TABLE 9. SUMMARY OF CATALYST EXHAUST TEMPERATURES DURING 13-MODE TESTING

		Catalyst Exhaust Temp, °C(°F)[d]		
Mode	Condition	Test 1[a]	Test 2[a]	Test 3[b]
1	Idle	313(595)	204(400)[c]	266(510)
2	1600/2	270(518)	196(384)	267(516)
3	1600/25	284(544)	286(546)	292(558)
4	1600/50	324(616)	339(643)	343(650)
5	1600/75	401(753)	433(812)	434(813)
6	1600/100	537(999)	540(1004)	544(1012)
7	Idle	408(767)	313(595)[c]	299(570)[c]
8	2200/100	512(954)	519(967)	522(972)
9	2200/75	450(842)	462(863)	457(855)
10	2200/50	387(728)	383(722)	383(722)
11	2200/25	341(645)	336(636)	340(644)
12	2200/2	317(603)	307(585)	307(585)
13	Idle	271(520)	204(400)[c]	368(515)

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[a] Temperature of right catalyst exhaust
[b] Average temperature of both catalyst units
[c] Taken after 4.5 minutes in mode
[d] Catalyst light-off temperature approx. 200°C (392°F)

An average of composite 13-mode emissions from Tests 1 and 3 yielded HC of 0.24, CO of 0.39 and NO_x of 9.13 g/kW-hr with a BSFC of 0.624 kg methanol/kW-hr. These results do not agree with the reference data provided by M.A.N. and given in Table 8 for this engine. Although the levels of hydrocarbon were about the same, SwRI results for CO were about 58 percent below, and NO_x were 58 percent above the levels provided by M.A.N.

Emission test documentation was checked, and no fault could be found with instrumentation or associated data processing. Potential reasons for these differences may be related to differences in instrumentation. The reference data provided by M.A.N. and given in Appendix Table A-1 indicates that the CO instrument used by M.A.N. may not have been as sensitive as that used by SwRI, and that M.A.N. determined NO_x by measuring NO with an NDIR instrument without an NO_2 to NO converter. In addition, it was noted that both "2 percent load" conditions (mode 2 and mode 12) reported by M.A.N. were actually run at considerably more than 2 percent load. Without extensive comparisons as to emissions measurement and computational methods, comparison of SwRI 13-mode emission levels to M.A.N. emission levels is difficult.

Emission concentrations determined with the partially failed catalyst showed significantly higher HC and CO, particularly during the light load conditions. This difference resulted in composite HC and CO levels 3 times higher than with the functional catalyst. Results from upstream of the catalyst during the third 13-mode test indicated extremely high levels of both HC and CO, showing that the functional catalyst was quite effective in oxidizing these species. Catalyst efficiencies with the new catalyst were 97, 96, and 1 percent for HC, CO, and NO_x, respectively. HC emission before the catalyst was 40 times that after the catalyst. Assuming that the bulk of these HC species were unburned methanol and applying the combined correction for the molecular weight of methanol and HFID response would increase the before catalyst HC level on a mass basis from 7.89 g/kW-hr to about 23 g/kW-hr. The CO emission before the catalyst was 27 times that after the catalyst. As expected, no change in NO_x emissions or fuel consumption was noted with changes in catalyst efficiency. The average BSFC from all 13-mode tests conducted by SwRI was 0.628 kg methanol/kW-hr. The ratio of lower heating values of diesel to methanol is 2.172 which results in a diesel equivalent BSFC of 0.289 kg diesel/kW-hr.(18)

b. Transient FTP

Transient emissions were measured and calculated in accordance with the 1984 Transient Federal Test Procedure and the 1986 Proposed Transient Federal Test Procedure (which includes particulate). As with the 13-mode test results, special consideration must be given to the reported emission levels due to the consumption of oxygen-containing fuel and the lower HFID response to unburned methanol which makes up a portion of the exhaust. The combustion products of alcohols also include more water than those of distillates due to the higher fraction of hydrogen present in the fuel. No additional corrections to CO concentrations were applied to account for the higher relative water vapor present in the CVS dilute exhaust sample. Absence of this correction has been shown to result in about 2 percent overstatement of CO emission.(17) No additional correction was applied to the calculation typically used to determine the dilution factor correction. Absence of this correction has been shown to result in about a 2 percent, or less, understatement of HC, CO, and NO_x emission level when CO_2 concentration is 2 percent or less.(17)

The influence of this potential error on dilution factor increases significantly as the difference between the sample and the background diminish, but as the emission level approaches the background level, although the percent of error may be large, the effect on the absolute value reported will be insignificant. Transient HC mass emissions reported here were based on a HC density of 0.5768 kg/m^3 (16.33 g/ft^3) as per the 1984 Transient FTP which is based on an assumption of diesel fuel-like exhaust HC species. No correction was applied to HFID response to unburned methanol. A "percent of fuel carbon" value for the methanol was entered as 37.5 percent for use in fuel consumption calculations by carbon balance. The NO_x correction factor was not applied since intake humidity and temperature were controlled to specified limits.

A transient power map of the engine was conducted using 13-mode intake and exhaust restrictions. The resulting rpm and torque data used to generate the control program are listed in Table B-1 of Appendix B. In addition, the work called for by the command cycle has been listed for each cycle segment along with the total of all four segments. Preliminary transient cycles were conducted and the dynamometer/engine controls were adjusted to improve the statistical results.

The results from three Transient FTP sequences are given in Table 10, and include transient composite emissions results as well as average transient composite levels of HC, CO, NO_x and particulate. Computer printouts corresponding to the individual cold-start and hot-start tests processed with continuous and bag NO_x are given in Appendix Tables B-2 through B-7. These printouts present the data on a test segment basis, which indicates the relative contributions from the various test segments. Statistical results for these tests, T-15 through T-20, are given in Appendix Table B-8. Although particulate is presented in Table 10, discussion of these transient particulate levels will be reserved for later.

The first Transient FTP run for regulated emission purposes was sequence T-15 and T-16, representing a cold- and hot-start, respectively. Some unregulated gaseous emission samples were taken during these runs. No operational problems were encountered, and the statistical criteria indicated that both cold- and hot-start tests were valid. Cold-start T-17 and hot-start T-18 were run the next day for regulated and unregulated gaseous emissions. Although the engine operated well, the hot-start test failed the statistical criteria for the power intercept and total power output. This result was primarily due to substantial torque output during the dynamometer-controlled 500 rpm idle which occurred in the last test segment of the transient cycle. An adjustment to the appropriate dynamometer controls was made, and another Transient FTP was scheduled. Cold-start and hot-start transient cycles T-19 and T-20 were conducted without any problems, and both tests passed the statistical criteria.

Emissions of HC and CO over both cold- and hot-start transient testing were both low primarily due to the use of the catalyst. During the cold-start, the catalyst exhaust temperature reached 200°C

TABLE 10. REGULATED EMISSIONS SUMMARY FROM TRANSIENT FTP OPERATION OF THE M.A.N. D2566 FMUH ENGINE ON NEAT METHANOL

Test No.	Cycle Type	Regulated Emissions,[a] g/kw-hr, (g/hp-hr)					Cycle BSFC[g] kg/kw-hr (lb/hp-hr)	Cycle Work kw-hr (hp-hr)
		HC[f]	CO	NO_x[b]	NO_x[c]	Part.		
T-15	Cold	0.19	0.80	8.91	7.21	0.08	0.796	9.19
	Start	(0.14)	(0.60)	(6.64)	(5.38)	(0.06)	(1.308)	(12.33)
T-16	Hot	0.05	0.40	9.30	7.71	0.06	0.711	9.36
	Start	(0.04)	(0.30)	(6.93)	(5.75)	(0.05)	(1.170)	(12.55)
	Transient	0.07	0.46	9.24	7.64	0.06	0.723	9.34
	Composite	(0.05)	(0.34)	(6.89)	(5.70)	(0.05)	(1.190)	(12.52)
T-17	Cold	0.47	0.80	8.08	6.87	0.07	0.753	9.43
	Start	(0.35)	(0.60)	(6.03)	(5.12)	(0.05)	(1.238)	(12.65)
T-18[d]	Hot	-0.03[d]	0.33[d]	8.71[d]	7.32[d]	0.06[d]	0.688[d]	9.68[d]
	Start	(-0.02)	(0.24)	(6.50)	(5.46)	(0.04)	(1.130)	(12.98)
	Transient	0.04	0.40	8.62	7.26	0.06	0.697	9.64
	Composite	(0.03)	(0.29)	(6.43)	(5.41)	(0.04)	(1.145)	(12.93)
T-19	Cold	0.38	0.74	8.01	7.20	0.05	0.762	9.12
	Start	(0.28)	(0.55)	(5.98)	(5.37)	(0.04)	(1.253)	(12.23)
T-20	Hot	-0.02	0.31	8.55	7.42	0.04	0.681	9.21
	Start	(-0.02)	(0.23)	(6.38)	(5.53)	(0.03)	(1.120)	(12.35)
	Transient	0.04	0.37	8.47	7.39	0.04	0.693	9.20
	Composite	(0.02)	(0.28)	(6.32)	(5.51)	(0.03)	(1.139)	(12.33)
	Average[e]	0.06	0.42	8.86	7.52	0.05	0.708	9.27
	Transient	(0.04)	(0.31)	(6.61)	(5.61)	(0.04)	(1.165)	(12.43)
	Composite							

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[a] Regulated emissions include HC, CO, NO_x, and particulate as proposed for 1986 Transient FTP

[b] NO_x values based on continuous measurement by chemiluminescence

[c] NO_x values based on bag measurement by chemiluminescence within 20 minutes of sample bag collection

[d] Failed statistical criteria on the basis of torque intercept and total power (>5% over command)

[e] Average Transient Composite values are based on the first and third transient composite

[f] HC mass was computed on the basis that measured HC species have a density of 16.33 g/ft^3 (as normally used for diesel fuel). In addition, no correction factor has been applied to HFID response to unburned methanol

[g] BSFC was computed on a carbon balance basis and assumes 37.5 percent fuel carbon

(392°F) after 60 seconds and during the hot-start this temperature was attained after only 50 seconds. Note that although catalyst exhaust temperature corresponded to the catalyst light-off temperature after only 60 seconds of transient operation, the maximum temperature reached over the transient cycle was only 427°C (800°F). By visually examining the catalyst exhaust temperature profile, the average catalyst temperature over the transient cycle was estimated at approximately 300°C (575°F).

Hydrocarbon emissions were actually lower than the background level in some instances, resulting in computed negative hydrocarbon emissions. Carbon monoxide emissions from the hot-start were half the level obtained from the cold-start, and were very low for either transient cycle. Levels of NO_x emissions were slightly lower for the cold-start than for the hot-start. As noted earlier, continuous NO_x measurement yielded about 15 percent higher NO_x levels than bag NO_x measurement. BSFC from the cold-start was slightly higher than from the hot-start, which has been typical of engines tested over the Transient FTP.(10)

Average transient composite values included results from the first and third Transient FTP's. In comparison to average 13-mode composite results, transient HC levels were about a third, CO levels were the same, and NO_x levels by continuous monitoring were 5 percent lower. Transient BSFC was 12 percent higher than 13-mode composite BSFC.

Converting the transient BSFC based on methanol to one based on diesel fuel yields a transient BSFC of 0.326 kg diesel fuel/kW-hr. This BSFC was considered to be higher than expected by M.A.N., and Mr. Chmela has since pointed out in a letter to EPA, given in Appendix C, that the methanol fueling schedule for this engine was set up for use with an automatic transmission. Unlike the transient test cycle, the automatic transmission does not load the engine below 800 rpm. During transient testing the engine tends to be overloaded and hence, overfueled below 800 rpm, which contributes to a higher than expected BSFC.

2. Selected Individual Hydrocarbons

Some individual hydrocarbons were determined from transient dilute exhaust samples using chromatographic techniques. They were methane, ethylene, ethane, acetylene, propylene, propane, benzene and toluene. Higher molecular weight hydrocarbons were not measured. Steady-state raw exhaust samples were collected in Tedlar bags in order to keep sample concentrations relatively high. Sample pump flow was maintained at a relatively high rate and seemed to prevent the formation of condensate in the sample line or pump.

Of all the individual hydrocarbons mentioned above, only methane was predominant in raw exhaust samples of steady-state operation. Aside from some ethylene (0.11 ppmC) detected during maximum power operation, no other of the individual hydrocarbons mentioned above were detected.

Table 11 gives the relative concentration of methane over the seven-mode samples. In all cases, the methane was lower than the background levels present in the intake air supply, and thus would be effectively zero.

TABLE 11. SUMMARY OF METHANE RAW EXHAUST EMISSIONS FROM M.A.N. D2566 FMUH METHANOL ENGINE (Not Corrected for Background)[a,b]

	RPM and Percent Load in Mode						
	1600	1600	1600		2200	2200	2200
Units	2%	50%	100%	Idle	100%	50%	2%
ppm	1.35	0.63	1.07	1.63	0.42	0.38	1.17
$\mu g/m^3$ exh	900	420	710	1100	280	250	670
mg/hr	430	200	350	160	190	160	420
mg/kw-hr	180	3	3	--	1	2	130
mg/kg-fuel	30	6	6	40	3	4	17

---

[a] Background Methane was 2.12 ppm, measured from air intake. All of the values reported in this table were below the background level.

[b] Ethylene was the only other individual hydrocarbon noted and occurred during the 2200 rpm/100% load mode. Quantities were as follows: 0.11 ppmC, 140 $\mu g/m^3$ exh., 96 mg/hr, 0.7 mg/kw-hr and 1.28 mg/kg fuel. No background ethylene was detected in the engine intake air.

In order to obtain a proportional sample over the transient cycle, a dilute exhaust sample was collected. Only methane was detected over the cold-start transient cycle as indicated in Table 12. None of the selected hydrocarbons were detected above the background level of the dilution air for the hot-start transient. Table 13 lists the minimum detection levels of the procedure used in this program.

TABLE 12. SUMMARY OF SELECTED HYDROCARBONS FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

	Transient IHC	
Methane	Cold-Start	Hot-Start
ppmC	0.16[a]	0[a]
$\mu g/m^3$	110	--
mg/test	70	--
mg/kW-hr	8	--
mg/kg fuel	10	--

---

[a] Corrected for background levels of methane (3.07 ppm) using a computed dilution factor of 20 on the basis of CVS gaseous emissions testing.

TABLE 13. MINIMUM DETECTION LEVELS OF THE IHC CHROMATOGRAPHIC PROCEDURE USED

Individual Hydrocarbon	Molecular Weight	$\mu g/m^3$ per ppm	Minimum Detection Value	
			ppm	$\mu g/m^3$
Methane	16.04	665	0.05	30
Ethylene	28.05	1165	0.03	30
Ethane	30.07	1250	0.03	30
Acetylene	26.04	1085	0.03	30
Propane	44.11	1835	0.02	30
Propylene	42.08	1750	0.02	30
Benzene	78.12	3245	0.01	30
Toluene	92.15	3830	0.01	30

3. Unburned Methanol

Since FID response is typically low for alcohols, it was important to determine the quantity of unburned methanol in the exhaust by another procedure. Unburned methanol was trapped in bubblers containing water, and processed through an appropriate chromatographic procedure. Table 14 summarizes the results from analysis of unburned methanol over seven modes of steady-state operation and includes catalyst exhaust temperatures.

TABLE 14. METHANOL EMISSIONS AND CATALYST OUT TEMPERATURE BY OPERATING CONDITION

	RPM and Percent of Load in Mode						
Units	1600 2%	1600 50%	1600 100%	Idle	2200 100%	2200 50%	2200 2%
$\mu g/m^3$ exh.	210000	17000	0	99000	0	25000	130000
mg/hr	100000	8200	--	15000	--	16000	81000
mg/kw-hr	42000	130	--	--	--	230	26000
mg/kg fuel	6500	240	--	3600	--	340	3300
Cat. Temp. °F	512	675	1020	440	980	730	610

Composite Unburned Methanol	0.527 g/kW-hr
	0.813 g/kg fuel

As is the case with typical diesel engines, most unburned fuel-like species were emitted during light load operating conditions (idle and 2 percent load conditions). During these conditions, the engine operated at low f/a ratios, and exhaust temperatures were relatively low. Although the catalyst exhaust temperatures were above the 200°C light-off temperature, there was apparently insufficient heat and mixing to oxidize all of the unburned fuel. No unburned methanol was detected at either 100 percent load condition, where exhaust heat and catalyst temperature were high. Seven-mode composites of methanol emission were computed as 0.530 g/kW-hr and 0.810 g/kg fuel on a brake specific and fuel specific basis, respectively.

Results from transient FTP testing are given in Table 15, and show unburned methanol levels obtained over repeat runs. Levels from the two cold-starts were different, whereas the hot-starts repeated quite well. At first the differences between the two cold-starts were thought to be due to inaccuracy of sampling, but it appears that these results coincide with corresponding HFID measurements of total hydrocarbons. Transient composites were 0.91 g/kW-hr and 1.24 g/kg fuel, and were about double the 7-mode composite level.

TABLE 15. UNBURNED METHANOL FROM TRANSIENT OPERATION
OF THE M.A.N. D2566 FMUH METHANOL ENGINE

	Transient Cycle					
	Cold Start			Hot Start		
Units	Test T-15	Test T-17	Avg.	Test T-16	Test T-15	Avg.
mg/test	11000	23000	17000	7400	6700	7050
mg/kw-hr	1200	2500	1850	790	710	750
mg/kg fuel	1600	3200	2400	1100	1000	1050

Composite Unburned Methanol 0.91 g/kw-hr
1.24 g/kg fuel

4. Aldehydes

Aldehydes were determined by the DNPH procedure, which detects formaldehyde, acetaldehyde, acetone, isobutyraldehyde, methylethylketone, crotonaldehyde, hexanaldehyde, and benzaldehyde. Samples were taken from dilute exhaust during transient operation, while samples of raw exhaust were taken during steady-state operation. The procedure was intended for use with raw exhaust, and it is difficult to obtain a concentrated sample from the dilute exhaust within the 20 minute duration of the transient cycle. Samples were taken over 7 modes of the 13-mode steady-state procedure. Table 16 gives the minimum detectable levels for this procedure.

A summary of aldehyde results from steady-state operation is given in Table 17. Of the compounds detectable by DNPH procedure, only formaldehyde was prevalent during light load conditions (2 percent load and idle). Very small amounts of methylethylketone were noted at both the 2 percent load conditions. These were the same operating conditions where unburned methanol concentrations were high and exhaust temperatures were low. No aldehydes were detected over the other four modes of higher

TABLE 16. MINIMUM DETECTABLE VALUES OF THE DNPH PROCEDURE

Compound	Molecular Weight	$\mu g/m^3$ per ppm	Min. Detection Value	
			ppm	$\mu g/m^3$
Formaldehyde	30.03	1250	0.01	15
Acetaldehyde	44.05	1830	0.01	20
Acetone	58.08	2415	0.01	25
Isobutyraldehyde	72.11	3000	0.01	30
Methylethylketone	72.12	3000	0.01	30
Crotonaldehyde	70.09	2915		--
Hexanaldehyde	100.16	4165	0.01	40
Benzaldehyde	106.13	4415	--	--

TABLE 17. SUMMARY OF ALDEHYDES FROM MODAL OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

		Emissions by RPM and Percent of Load in Mode						
	Units	1600 2%	1600 50%	1600 100%	Idle	2200 100%	2200 50%	2200 2%
Formaldehyde	$\mu g/m^3$ exh	25000	N.D.[a]	N.D.[a]	3000	N.D.[a]	N.D.[a]	24000
	mg/hr	12000			440			15000
	mg/kW-hr	5100			--			4900
	mg/kg fuel	780			110			610
Methylethyl-ketone	$\mu g/m^3$ exh	55	N.D.[a]	N.D.[a]	N.D.[a]	N.D.[a]	N.D.[a]	530
	mg/hr	26						330
	mg/kW-hr	11						110
	mg/kg fuel	117						13

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[a] N.D. = Not Detected

power operation. Seven-mode composite brake specific and fuel specific aldehydes were 61 mg/kW-hr and 95 mg/kg fuel, respectively.

In addition, raw exhaust samples generated with the partially failed catalyst were processed and the results are given in Table 18. Levels of formaldehyde were 3 times higher during the 2 percent load conditions and 7 times higher during idle than with the replacement catalyst. This comparison illustrates the importance of insuring and maintaining a properly functioning ignition system and oxidation catalyst for this engine.

TABLE 18. FORMALDEHYDE FROM MODAL OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE WITH PARTIALLY FAILED CATALYST[a]

	RPM And Percent of Load In Mode		
	1600		2200
Units	2%	Idle	2%
$\mu g/m^3$ exh	73000	52000	69000
mg/hr	35000	7600	43000
mg/kW-hr	15000	--	14000
mg/kg fuel	2300	1800	1700

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[a] Catalyst had apparently deteriorated due to temperature excursion caused by loss of ignition control module. These were the only three modes for which aldehydes were detected.

Replicate dilute exhaust samples were taken over both the cold- and hot-start transient cycles. Results from analysis indicated no aldehydes above the minimum detectable levels, as given in Table 19. Since no aldehydes were detected in the CVS dilute exhaust, non-proportional samples were taken from the raw exhaust over cold- and hot-start transient cycles. These non-proportional samples tended to overstate idle contributions and understate higher exhaust rate conditions. From the non-proportional samples, formaldehyde in concentrations of 0.62 ppmC (or 95 mg/test, 10 mg/kW-hr and 13 mg/kg fuel) were obtained over the cold-start. No formaldehyde was detected over the hot-start transient cycle. The small amount of formaldehyde noted from the cold-start was likely formed during the initial light-off of the catalyst.

TABLE 19. SUMMARY OF ALDEHYDES FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE BASED ON NON-PROPORTIONAL SAMPLE OF RAW EXHAUST

	Transient Aldehydes	
	Cold Start	Hot Start
Formaldehyde		
ppmC	0.62	(0.01)[a]
mg/test	95	(10)
mg/kW-hr	10	(1.1)
mg/kg fuel	13	(1.6)

---

[a] Values in parentheses illustrate the detectable limits of aldehydes over the transient cycle and represent cycles over which aldehydes were not detected.

5. Phenols

Phenols were determined using a wet chemistry procedure as outlined in Section III, E.1. and described in detail in Reference 11. Dilute exhaust samples were collected over the transient cycle only. The detection of individual phenols in dilute or raw exhaust is quite variable. The respective minimum detection levels are given in Table 20. Analysis of the dilute exhaust samples collected over the transient cycle indicated that only 2,3,5,6-tetramethylphenol was present. This phenol has the highest molecular weight of any of the phenols separable by the procedure, and is difficult to quantify due to interference. Levels of 1.9 μg/m^3 and 0.6 μg/m^3 were indicated for the cold- and hot-start, respectively, but their presence is doubtful.

TABLE 20. MINIMUM DETECTABLE VALUES OF PHENOLS PROCEDURE

Phenol Group	Molecular Weight	μg/m^3 per ppm	Min. Detection Value	
			ppm	μg/m^3
Phenol	94.1	3915	0.002	6
Salicylaldehyde	122.1	5080	0.002	12
m-cresol p-cresol	108.2[a]	4499[a]	0.001[a]	6[a]
p-ethylphenol 2-isopropylphenol 2,2-xylenol 3,5-xylenol 2,4,6-trimethylphenol	127.8[a]	5316[a]	0.002[a]	12[a]
2-n-propylphenol	136.2	5666	0.001	6
2,3,5,-trimethylphenol	136.2	5666	0.002	12
2,3,5,6-tetramethylphenol	150.2	6249	0.002	12

---

[a] average

6. Total Hydrocarbons

As mentioned in the discussion of hydrocarbon emissions over both steady-state and transient testing, hydrocarbons indicated by HFID may be significantly understated due to poor FID response and due to calculations using a molecular weight of 13.88 per carbon atom to represent the exhuast HC species. In order to obtain a more representative total hydrocarbon emission level, the sum of all hydrocarbon-containing species determined by specialized analysis may be used to determine actual total of hydrocarbons. Using 7-mode composite values, the actual total of hydrocarbons, on a brake specific basis, would be 0.59 g/kW-hr as compared to 13-mode HFID total hydrocarbons of 0.24 g/kW-hr reported earlier. Similarly, the transient composite of actual total hydrocarbons would be 0.91 g/kW-hr as compared to transient HFID total hydrocarbons of 0.06 g/kW-hr. Over both steady-state and transient operation, the dominant contributor to the actual total of hydrocarbons was unburned methanol.

7. Odor-TIA

TIA results were determined using the DOAS analysis of traps which collected compounds related to odor intensity.(8,10) This chromatographic procedure separates an oxygenate fraction (liquid column oxygenates, LCO) and an aromatic fraction (liquid column aromatics, LCA). The TIA values are defined as TIA = 1 + $\log_{10}$ (LCO, μg/ℓ), or TIA = 0.4 + 0.7 $\log_{10}$ (LCA, μg/ℓ), (TIA by LCO preferred). The procedure was developed for steady-state raw exhaust samples, but was adapted to transient dilute exhaust samples by use of the CVS. Table 21 summarizes the results from 7 modes of steady-state operation and Table 2 gives results from transient operation. A computed 7-mode composite of TIA was 1.30, slightly lower than the transient composite of 1.61.

TABLE 21. SUMMARY OF TIA BY DOAS FROM MODAL OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Modal Condition rpm/load, %	LCA, μg/ℓ	LCO, μg/ℓ	TIA
1600/2	0.96	3.14	1.48
1600/50	1.97	4.86	1.67
1600/100	0.55	2.61	1.40
Idle	1.49	1.99	1.27
2200/100	0.42	1.38	1.07
2200/50	0.96	2.00	1.29
2200/2	4.19	--	0.84[a]

Based on comparison to standards developed by ADL

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[a] Determined from LCA - all others based on LCO

TABLE 22. SUMMARY OF TIA BY DOAS[a] FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Transient Cycle	LCA, μg/ℓ	LCO, μg/ℓ	TIA
Cold Start	0.24	4.37	1.64
Hot Start	0.78	4.02	1.60
Transient Composite	0.70	4.07	1.61

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[a] These measurements were based on ADL standards, TIA values computed on basis of LCO.

C. Particulate Emissions

Although heavy-duty diesel particulate emissions are not scheduled to be regulated until 1986, they have been measured for some time and have been recognized as a potential problem in the application of diesel engines. Since the test engine is considered an alternative to conventional diesels, its particulate emissions were characterized for purposes of comparison. In order to determine particulate emission rates and to characterize the total particulate, samples were collected on several filter media for a variety of analyses which included total mass, elemental analysis, particle sizing, and organic extractables. Particulate samples were always taken from the dilute exhaust using a CVS. The dilution tunnel, probes and filter holders were cleaned prior to particulate sampling from this engine.

1. Total Particulate

Total particulate emissions over 7 modes of steady-state operation are given in Table 23. The highest particulate emission was 3.4 g/hr during the 2 percent load/2200 rpm condition, and the lowest was 0.04 g/hr during idle. These emissions are extremely low relative to diesel engines of the same size which typically emit from 200 g/hr during maximum load condition to about 4 g/hr during idle conditions. Examining the filters visually, it was often difficult to tell if a given filter had been used. Brake specific and fuel specific 7-mode composites of total particulate emissions were calculated as 0.024 g/kW-hr and 0.037 g/kg fuel, respectively.

TABLE 23. PARTICULATE EMISSION SUMMARY FROM MODAL OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Condition	Steady-State Particulate			
rpm/load, %	mg/m^3 exh.	g/hr	g/kw-hr	g/kg fuel
1600/2	1.66	0.793	0.335	0.051
1600/50	1.77	0.857	0.014	0.025
1600/100	1.68	0.827	0.007	0.013
Idle	0.28	0.041	--	0.010
2200/100	2.82	1.93	0.014	0.026
2200/50	3.21	2.11	0.030	0.045
2200/2	5.41	3.38	1.09	0.137
7-mode Composite	2.71	1.32	0.024	0.037

Particulate emissions from transient testing along with transient composite particulates are shown in Table 24, and were given in Table 10 along with transient regulated emissions. As with modal testing, transient particulate emissions were extremely low. Based on lightly-loaded 90 mm filter weight gains, less than 1 milligram, computation of average brake specific particulate over the cold- and hot-start transient cycles yielded 0.066 g/kW-hr and 0.056 g/kW-hr, with an average transient composite of 0.057 g/kW-hr. On a fuel specific basis, cold-start particulate emission was 0.086 g/kg fuel, the hot-start was 0.080 g/kg fuel; with an average transient composite of 0.081 g/kg fuel. Similar to modal particulate collection, no carbon black was noted on any of the filters, although a slightly perceptible discoloration of the used filters was noted. Filter efficiency of the 90 mm Pallflex filters averaged 81 percent during the cold-start and 83 percent during the hot-start.

TABLE 24. PARTICULATE SUMMARY FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

	Transient Particulate, g/kW-hr		
Test No.	Cold-Start	Hot-Start	Composite
T-15, T-16	0.077	0.063	0.065
T-17, T-18	0.066	0.059	0.060
T-19, T-20	0.055	0.045	0.046
Avg.	0.066	0.056	0.057

2. Smoke

Smoke and particulate emissions are related, smoke level being a measure of the visible portion of particulate matter. Changes in particulate emissions may be indicated by corresponding changes in smoke opacity, if levels are high enough. Smoke opacity was determined using an end-of-stack smokemeter with 7.6 cm (3 inch) diameter exhaust stack. The smokemeter was zeroed, and calibration filters of 9, 24.5 and 44 percent opacity were used to check the accuracy of the smokemeter.

The transient Federal Smoke Cycle was programmed and run three consecutive times as specified in the Federal Register. Results indicated zero acceleration, zero lug, and zero peak smoke opacities. The smokemeter was recalibrated, and steady-state measurements were performed. Once again, zero smoke opacity was noted for all of the 13 modes of steady-state operation, and for the full power curve. Observation verified that no visible smoke was present.

3. Elemental Composition

Elemental analysis of the total particulate required two particulate samples. The carbon and hydrogen contents of the total particulate were determined from particulate samples collected on glass fiber filter media. Nitrogen content was also to be assessed, but total particulate was too low to provide a suitable sample for analysis. The relative contents of metals were determined from particulate samples obtained over the cold- and hot-start transient cycles, collected on Teflon membrane filter media (Fluoropore), and examined using X-ray fluorescence techniques. The carbon and hydrogen contents were determined by Galbraith Laboratories, and the metals were determined by EPA-RTP.

Table 25 gives the percent carbon and hydrogen contained in samples of total particulate collected over steady-state engine operation. In addition to carbon and hydrogen content, Table 26 gives the relative content of metal contained in samples of total particulate collected over cold- and hot-start transient operation.

TABLE 25. SUMMARY OF CARBON AND HYDROGEN CONTENT IN TOTAL PARTICULATE FROM MODAL OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Condition rpm/load	Element, Percent by Weight of Total Particulate	
	C	H
1600/2	52.5	10.9
1600/50	54.5	11.7
1600/100	24.8	12.8
Idle	88.0	11.8
2200/100	31.5	7.2
2200/50	63.3	11.3
2200/2	53.6	10.4

Note: These results based on analysis of total particulate collected on glass fiber filter media. In addition, accuracy is relative to the gross amount of particulate submitted. Although 2 mg of diesel particulate are desired, the average filter loading for the samples submitted was approx. 0.5 mg.

TABLE 26. SUMMARY OF ELEMENTAL ANALYSIS OF TOTAL PARTICULATE FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Cycle Type	Element, Percent by Weight of Total Particulate											
	C	H	S	Cl	Na	Mg	Al	P	K	Ca	Fe	Zn
Cold Start	75.6	13.7	2.18	0.30	a	0.60	0.19	0.65	0.27	0.84	a	1.53
Hot Start	82.7	14.9	0.91	0.09	b	0.19	0.04	0.26	0.02	0.31	a	0.48

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[a] Element was detected but was below the level of quantification

[b] Element was not detected

Total particulate from the idle condition had the greatest percentage of carbon and somewhat typical percentage of hydrogen, and resembles levels often found for oil or diesel fuel-like materials. The percentage of carbon was significantly lower for full load conditions. Carbon and hydrogen content of the total particulate from cold- and hot-start transient operation resembled that from the steady-state idle condition. Analyses for metals indicate significant quantities of S, P, Ca, and Zn present in the cold-start particulate, and to a lesser extent, in the hot-start particulate. These same species were also found in analysis of the used engine oil given in Table 27.

TABLE 27. ANALYSIS OF USED CRANKCASE OIL FROM THE M.A.N. D2566 FMUH METHANOL ENGINE

Viscosity @40°C, centistokes	99.03
Viscosity @100°C, centistokes	14.02
Pentane Insolubles, percent	0.04
Toluene Insolubles, percent	0.03
Total Acid Number, mg KOH/g sample	3.78
Total Base Number,[a]	6.90
Fuel Dilution (by G.C.), percent	0.16
Wear Metals, Additives, Contaminants by XRF, ppm	
Fe	27
Cu	11
Cr	<15
Pb	<60
Ca	900
Zn	1000
P	900
S	7700

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[a] 1.159 × (mg $HClO_4$ per gram sample)

4. Particle Size Distribution

Particle sizing by the Sierra Model 220 cascade impactor was used to obtain a particle size distribution from transient FTP operation. Since the particulate emissions on the transient cycle were extremely low and the cascade impactor operated with a very small flow rate, the impactor was loaded and a sample was collected over 1 cold-start and 6 hot-start transient cycles.

The particle size distribution resulting from this composite impactor set is plotted in Figure 8. No particles were noted for the first 4 stages of the impactor which correspond to 6.5, 4.0, 2.5 and 1.4 microns effective cut-off diameter (ECD). From Figure 8, 83 percent of the particles were found on the back-up filter after the last stage, which has a cut point of 0.06 micron ECD. Although the total loading was very small (0.088 mg), the calculated composite brake specific particulate rate from this impactor was computed as 0.054 g/kW-hr, which agrees well with the average transient composite value of 0.057 g/kW-hr as determined from 90 mm Pallflex filters. This correlation indicates that integrity of the sample was maintained. The back-up filter had only a faint discoloration and no evidence of carbon black.

5. Soluble Organic Fraction

The soluble organic fraction (SOF) of the total particulate was obtained from particulate samples collected on 20x20 inch Pallflex filters, using soxhlet extraction procedures with methylene chloride. The SOF has been reported as a percentage of the total particulate, and is referred to as percent solubles. This result gives an indication as to the nature of the total particulate matter, but makes it difficult to compare SOF emission rates of the various test configurations. Table 28 summarizes the SOF mass emissions and percent solubles from both modal and transient operation.

The percent of extractables indicated on the basis of total recovered extractables, including background extractables which contributed an average of 2.33 mg per filter processed, ranged from about 84 percent for both 2 percent load conditions to about 21 percent for the full load intermediate speed condition. The background contribution to the indicated total percent solubles is also given in Table 28. The engine contribution was calculated by subtracting the background contribution from the indicated total. The engine contribution to the total SOF is hence used in calculations of soluble particulate emissions.

Over steady-state operation, the percent extractables ranged from a high of about 80 percent for both 2 percent load conditions to a low of about 14 percent for the full load intermediate speed condition. On a mass rate basis, a maximum of 2.7 g/hr of engine derived soluble organics was emitted during the 2 percent load/2200 rpm condition, and a minimum of 0.017 g/hr was emitted during the idle condition. A 7-mode composite of

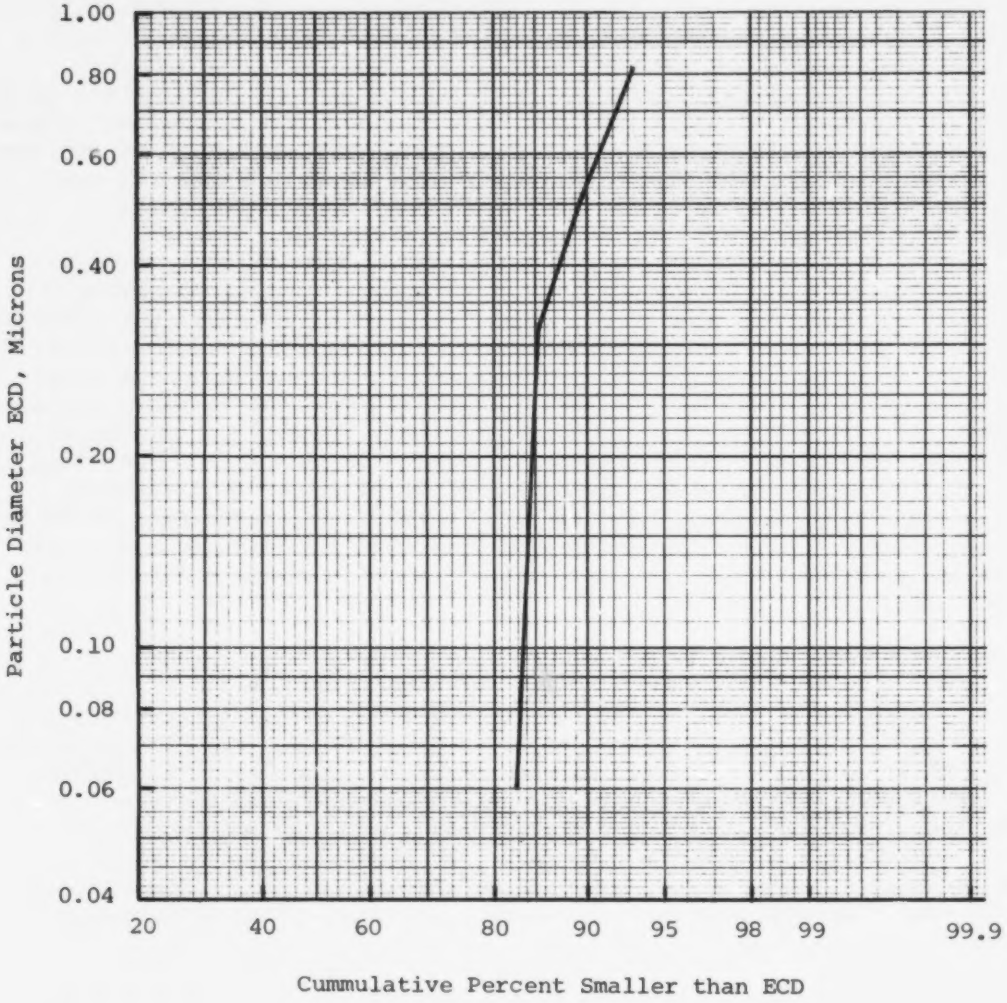

Figure 8. Particle size distribution from transient operation of the M.A.N. D2566 FMUH Methanol Engine

TABLE 28. SUMMARY OF SOLUBLE ORGANIC FRACTION FROM OPERATION OF M.A.N. D2566 FMUH METHANOL ENGINE

	Solubles from Steady-State Operation						
	Percent Solubles in Total Particulate,%			Engine Soluble Particulate Emission			
Steady-State Condition rpm/load	Indicated Total	Background Contribution	Engine Contribution	g SOF/hr	g SOF/kW-hr	g SOF/kg fuel	Background Contribution to SOF %
1600/2	85.1	4.9	80.2	0.636	0.268	0.0412	5.7
1600/50	58.4	10.2	48.2	0.413	0.00656	0.0120	17.5
1600/100	20.8	7.1	13.8	0.114	0.000901	0.00181	33.9
Idle	61.1	20.1	41.0	0.017	--	0.00410	32.8
2200/100	33.1	3.6	29.4	0.567	0.00399	0.00756	11.0
2200/50	70.0	2.9	67.2	1.418	0.0301	0.0303	4.1
2200/2	83.2	2.3	81.0	2.738	0.833	0.111	2.8
7-Mode Composite	--	--	59.3	0.783	0.0144	0.0223	--
	Solubles from Transient Operation						
Cold Start	83.0	13.4	69.6	NA	0.0459	0.0596	16.1
Hot Start	95.6	3.5	75.4	NA	0.0422	0.0609	4.6
Composite	--	--	74.9	NA	0.0427	0.0607	6.2

Note: Since extractables were relatively low, engine soluble emissions were computed using engine contributed solubles, which have been corrected for background extractables derived from a blank filter from the same batch used during this program. There were 2.33 mg extractables per 20×20 filter used.

the percent extractable was 59.3 percent, which is equivalent to 0.78 g/hr, or 0.014 g/kW-hr. Extractables were determined for transient operation as well. Engine derived percent extractables were 69.6 percent and 75.4 percent for the cold- and hot-start cycles, respectively. These values translate into brake specific SOF emission rates of 0.046 and 0.042 g/kW-hr for the cold- and hot-start, respectively. The transient composite of solubles was 75 percent SOF and 0.043 g/kW-hr.

Although the background contribution to SOF may be backed-out by calculation, samples of SOF submitted for analysis contained a portion of background SOF. The background portion of SOF in the samples ranged from 34 to 2.8 percent, and is tabulated in Table 28. A cold- and hot-start composite sample was submitted for Ames testing, and approximately 6.2 percent of the SOF sample was background SOF. Samples of SOF were also submitted for analysis of BaP, boiling range, HPLC fractionation and elemental C, H, and N content. In addition, a sample of used oil was carried through the filter extraction process and was analyzed for BaP and Ames response.

a. Elemental composition

Organic solubles from cold- and hot-start transient operation of the methanol engine were analyzed for carbon, hydrogen and nitrogen content. Table 29 lists the elements as percentages of the soluble organic fraction. There was no appreciable difference between the cold- and hot-start results with respect to carbon and hydrogen, but the nitrogen content was significantly higher for the cold-start extractables.

TABLE 29. ELEMENTAL COMPOSITION OF SOLUBLE ORGANIC FRACTION FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Cycle Type	SOF g/kW-hr	Element, Percent of SOF		
		C	H	N
Cold	0.046	83.7	12.7	0.74
Hot	0.042	85.0	13.5	0.08

b. Boiling Point Dsitribution

A high-temperature GC-simulated boiling point distribution was conducted on SOF from several of the steady-state operating conditions, as well as from cold- and hot-transient operation. There was not enough extract to support the addition of an internal standard (C_9 - C_{11}), in most cases; however, three samples were run with an internal standard. The numerical results of these analyses are presented in Table 30. Samples with internal standard showed recovery ranging from 90 to 94 percent, whereas, those run without internal standard were assumed to have been completely volatilized. Since a portion of the SOF was suspected of

TABLE 30. BOILING POINT DISTRIBUTION OF SOLUBLE ORGANIC FRACTION FROM TRANSIENT OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Test Condition	Sample Code	Boiling Temperature at Distillation Point, °C											Recovery, %
		IBP	10	20	30	40	50	60	70	80	90	EP	
1600/2	S-199	339	405	418	429	439	449	460	473	490	514	604	100
1600/50	S-204	317	401	417	429	441	452	465	480	498	524	610	100
2200/100	S-212	329	410	424	433	442	452	463	476	495	523	632	100
2200/50	S-216[a]	354	416	430	441	452	464	478	496	520	583	---	91
2200/2	S-221[a]	344	409	424	435	448	460	474	494	521	628	---	90
Cold Start	S-226	319	394	412	425	437	448	460	475	494	521	622	100
Hot Start	S-230[a]	331	407	421	434	445	458	472	490	516	563	---	94
Used Oil	S-236	334	399	414	426	437	448	459	473	491	516	605	100

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[a] Run with internal standard

originating from the lubricating oil, a sample of used-oil-derived SOF was also processed. These boiling point distributions are graphically displayed in Figures 9, 10, and 11 for visual comparison. Sample codes are given along the right skewed axis of each figure and correspond to sample codes and corresponding sample labels given in Table 30. All the boiling point distributions appear to be similar and closely resemble that of the used-oil-derived SOF.

c. Fractionation by Relative Polarity

The composition of the soluble organic fraction of the total particulate is complex, and its separation into individual compounds is very difficult. Fractionation of the SOF by high performance liquid chromatography (HPLC) separates the soluble portion into a series of fractions of increasing molecular polarity. Figures 12 through 20 show the HPLC chormatographic outputs for direct comparison of the relative concentration of increasingly polar compounds from both steady-state and transient operation of the M.A.N. methanol engine.

Each figure contains two traces, one representing the fluorescence detector response, and the other representing the ultraviolet detector response. The fluorescence trace starts at time 0. The ultraviolet trace is scale offset by about 1 minute due to pen offset of the recorder. Initially, the solvent is composed of 95 percent hexane and 5 percent methylene chloride, a relatively non-polar mixture. This solvent mixture is used from the start of the chromatogram to 17 minutes into the elution period (designated by "^"). During this period, non-polar PNA compounds also elute and give ultraviolet and fluorescence responses. After 17 minutes, the polarity of the solvent is increased at a rate of 5 percent methylene chloride per minute. During this transition period of solvent polarity, more polar compounds are eluted, giving fluorescence and ultraviolet spectra. At the end of this solvent transition period (36 minutes into the run and designated by "^"), the solvent is 100 percent methylene chloride, and 9-fluorenone elutes. With 100 percent methylene chloride, even more polar compounds elute. Acridine elutes during this polar period (at about 70 minutes).

Figure 17 shows the trace resulting from the injection of the standard used during analysis of SOF derived from steady-state engine operation. The HPLC response to the standard solution properly identified the BaP region by both fluorescence and ultraviolet response (at 17 minutes) and the 9-fluorenone by ultraviolet response (at approximately 37 minutes). The two peaks of the ultraviolet response shown at about 40 and 44 minutes were caused by an unknown contaminant in the column used during processing. Similarly, the fluorescence peak noted around 29 minutes was also attributed to the peculiarities of the column.

The fluorescence responses for all of the SOF samples from steady-state operation are minimal. A very small peak may be noted for the fluorescence response at about 2-3 minutes elution time, where a

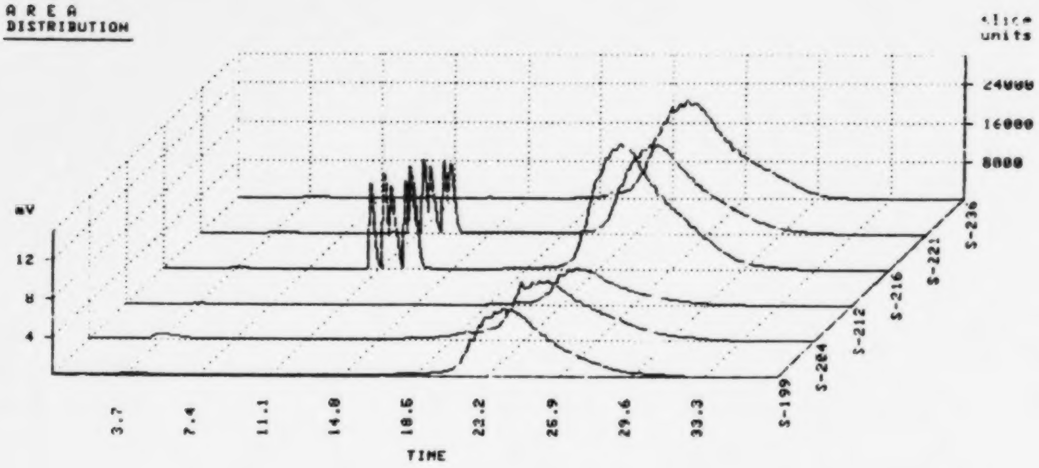

Figure 9. Boiling point distribution of SOF from modal operation of the M.A.N. methanol engine (along with extract from used crankcase oil)

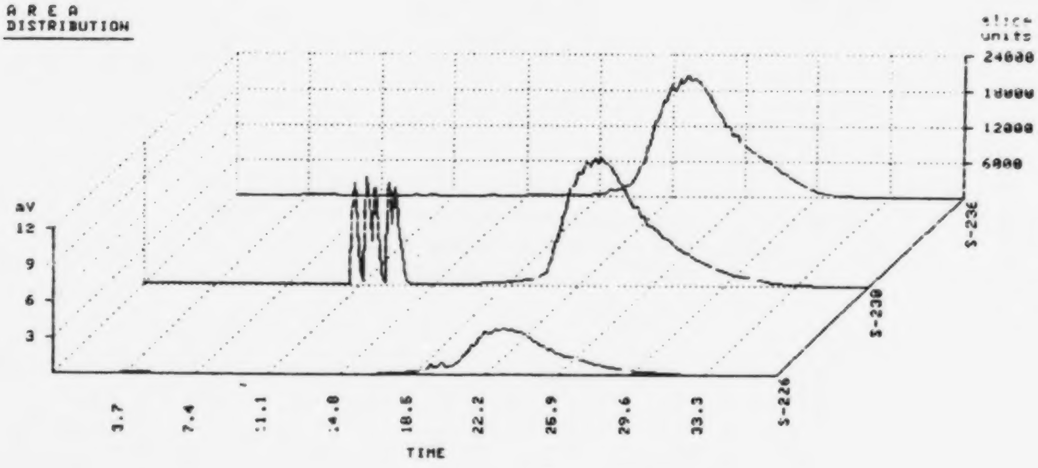

Figure 10. Boiling point distribution of SOF from transient operation of the M.A.N. methanol engine (along with extract from used crankcase oil)

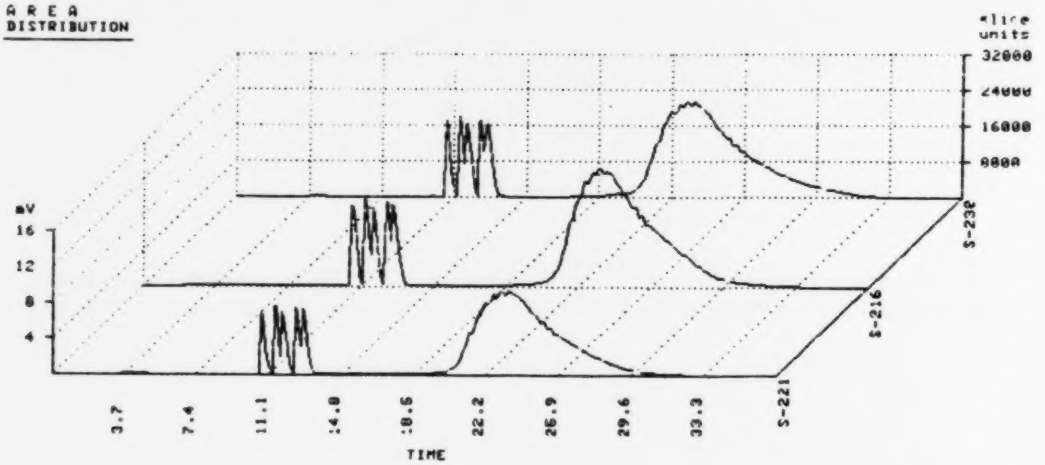

Figure 11. Boiling point distribution of SOF from the M.A.N. methanol engine run with internal standard

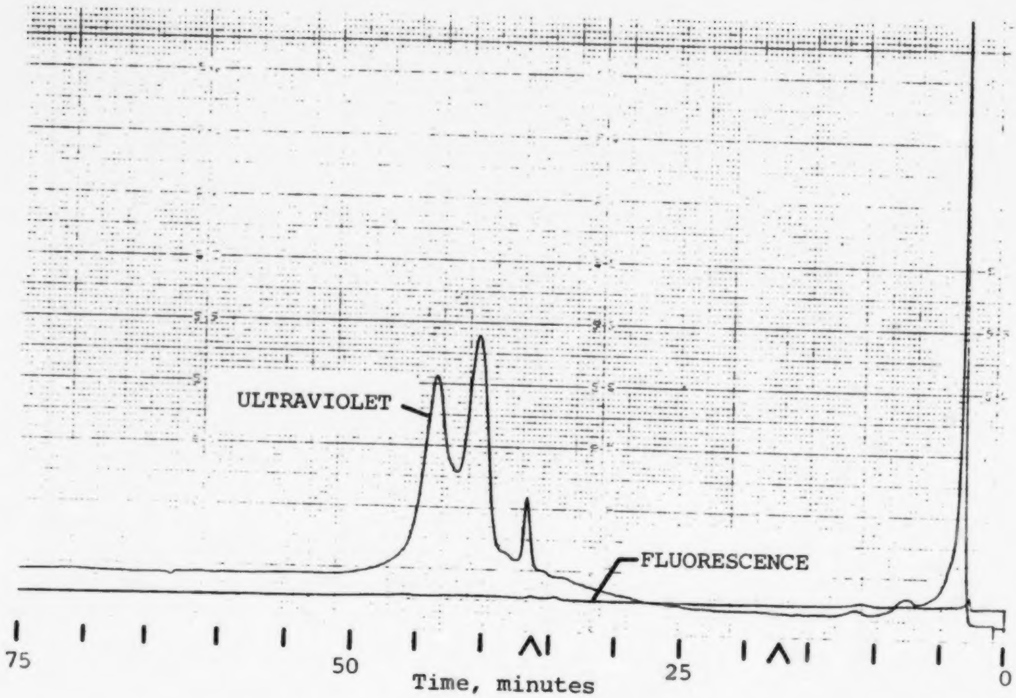

Figure 12. HPLC response to SOF from 1600 rpm/2 percent load operation

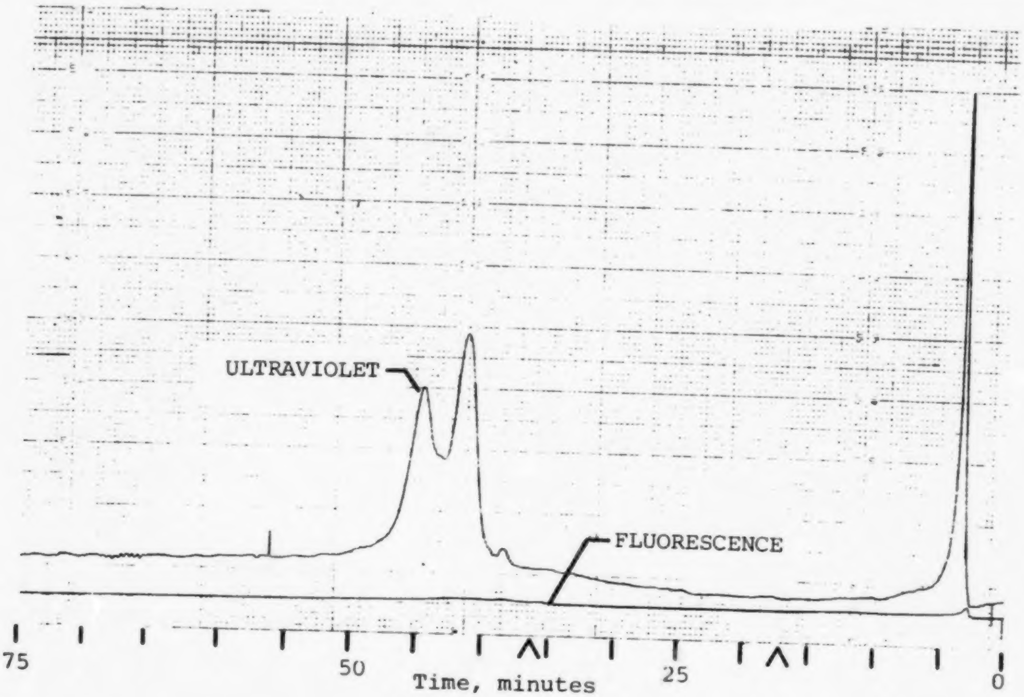

Figure 13. HPLC response to SOF from 2200 rpm/2 percent load operation

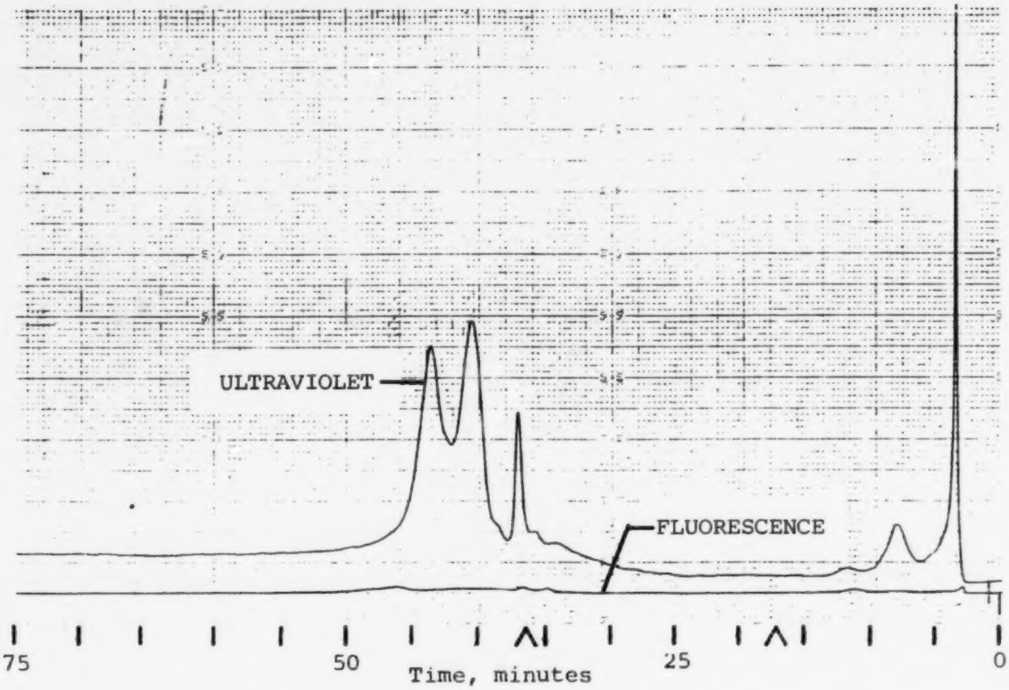

Figure 14. HPLC response to SOF from 1600 rpm/50 percent load operation

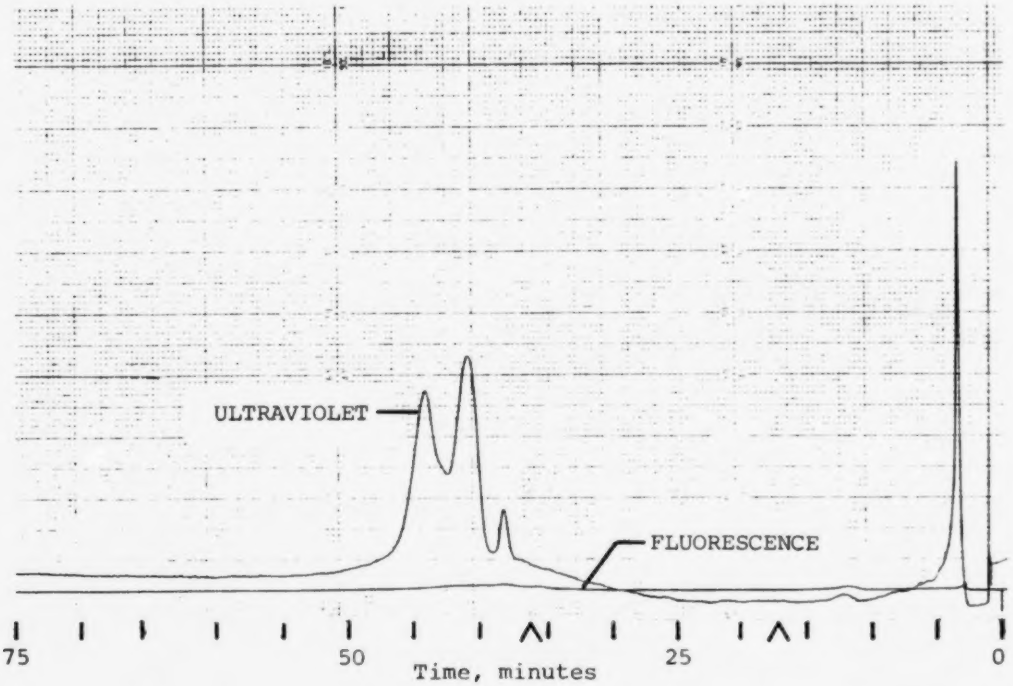

Figure 15. HPLC response to SOF from 2200 rpm/50 percent load operation

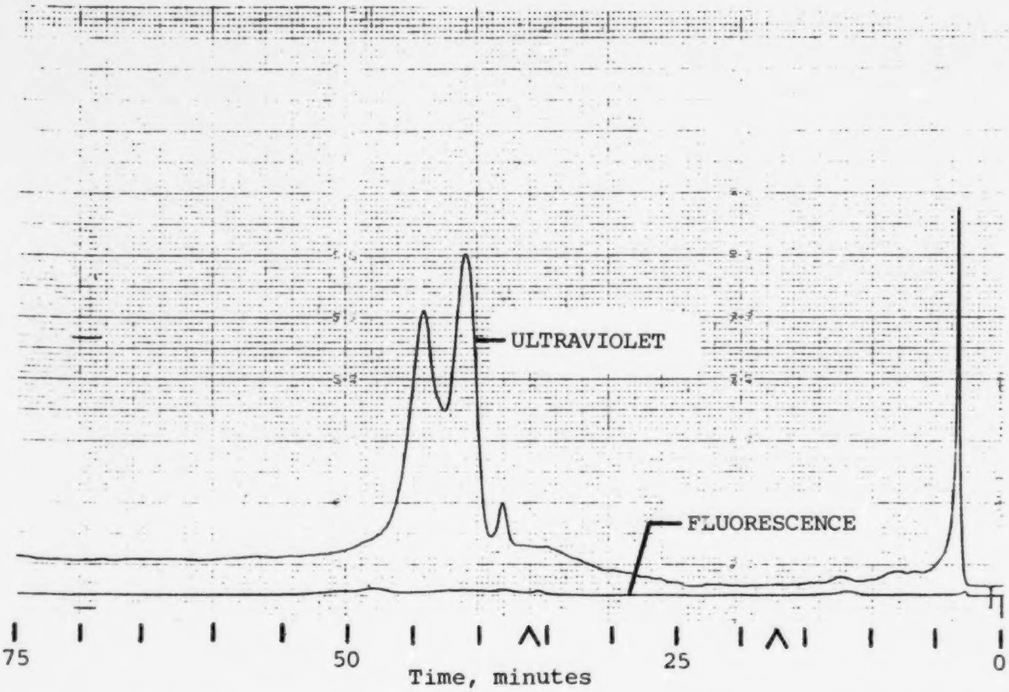

Figure 16. HPLC response to SOF from 2200 rpm/100 percent load operation

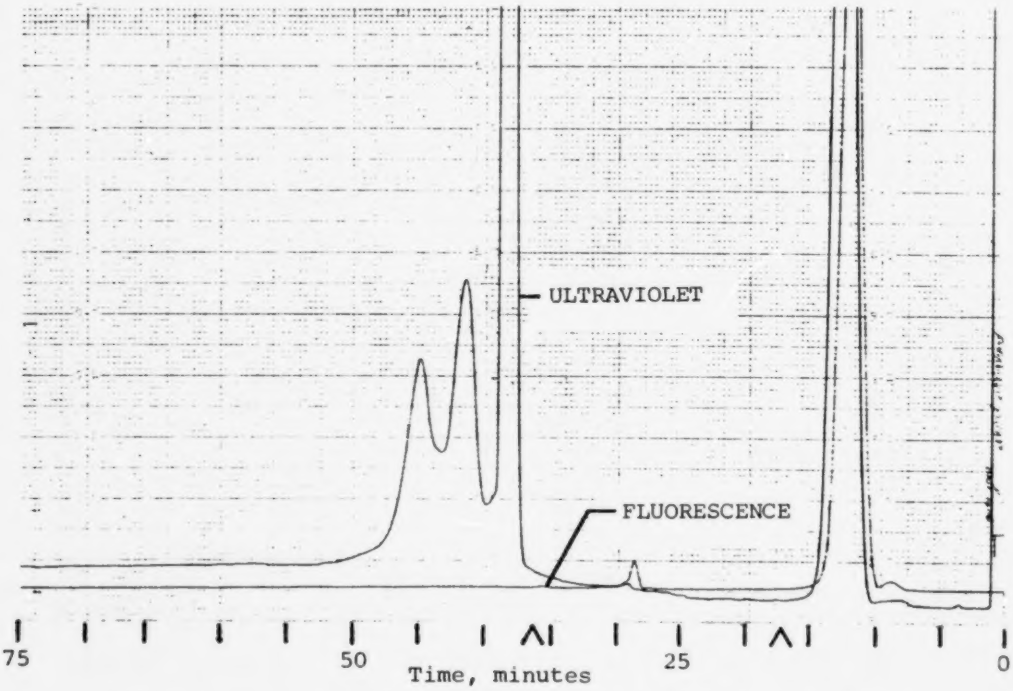

Figure 17. HPLC response to standard solution used during processing SOF derived from steady-state operation

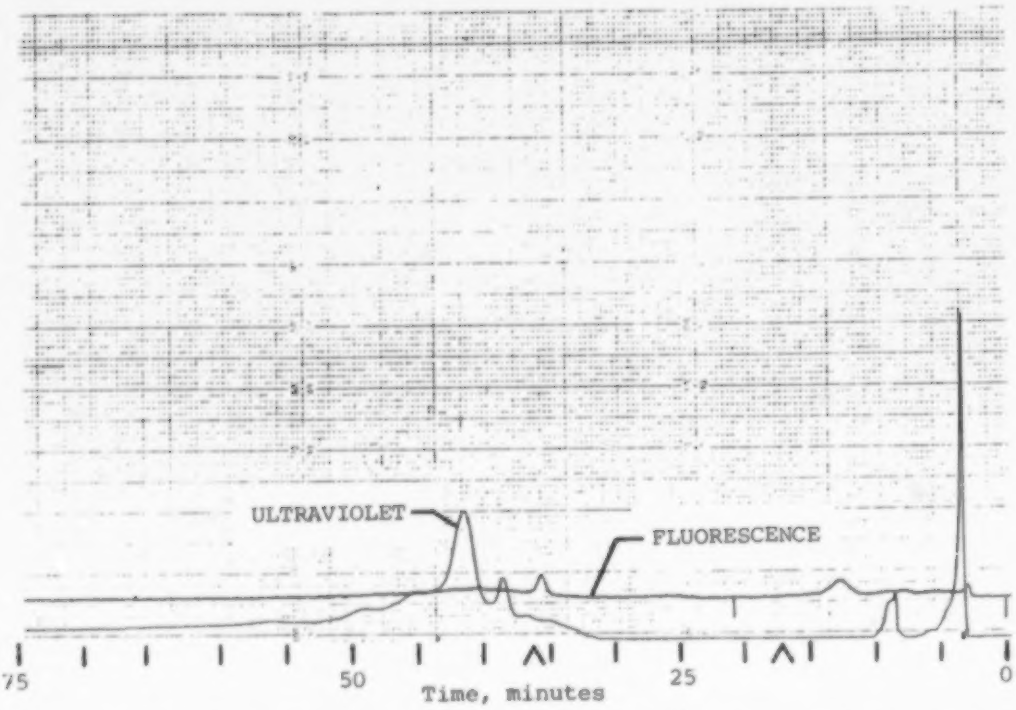

Figure 18. HPLC response to SOF from cold-start transient operation

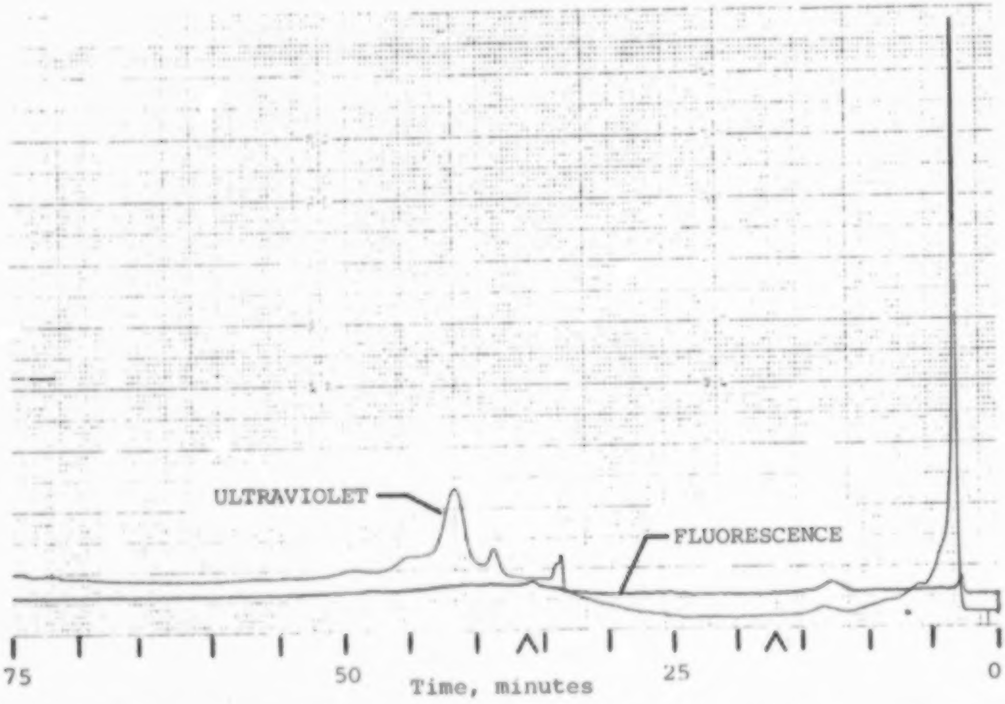

Figure 19. HPLC response to SOF from hot-start transient operation

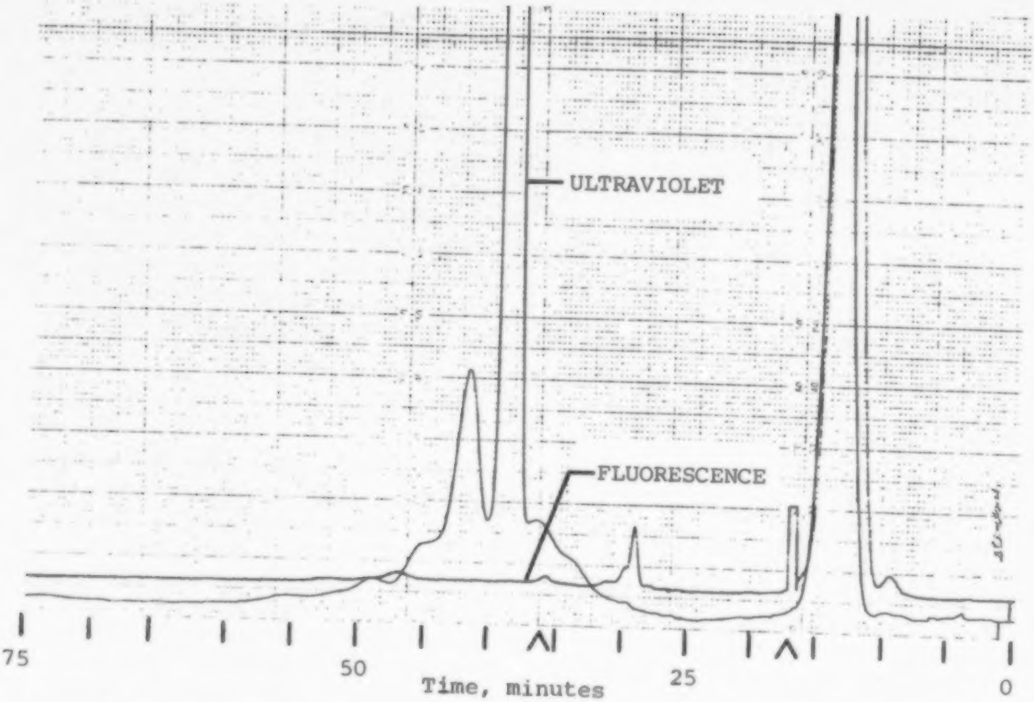

Figure 20. HPLC response to standard solution used during processing SOF derived from transient operation

significant untraviolet response was noted for all of the steady-state SOF samples at 2 minutes (pen offset = -1. minute). This relatively early response may indicate the presence of a straight chain hydrocarbon. The ultraviolet response also indicated unknown compounds at 7 minutes in Figures 12 and 14 (both 1600 rpm conditions). Only very small peaks in both the fluorescence and ultraviolet response were noted in the regions where BaP-type molecules are normally indicated by the standard. The ultraviolet response at 36-37 minutes indicates the presence of compounds similar to the 9-fluorenone. A portion of this repsonse may be due to the remnant of the standard solution. It is recommended that the peaks at 40 and 44 minutes be considered as column-oriented response and not indicative of the sample.

The fluorescence and ultraviolet response of the HPLC instrument to the standard solution used to process the SOF samples derived from transient operation is given in Figure 20 for reference. The fluorescence responses for both cold- and hot-start transient SOF were similar in that there were small peaks at approximately 3, 13, and 35-36 minutes. Similar to results from steady-state derived samples, the ultraviolet response had peaks at 2 and 12 minutes. Ultraviolet response peaks at 38 and 41 minutes may be the results of column interference or a remnant of the standard solution.

d. Benzo(a)pyrene

Benzo(a)pyrene (BaP) content was determined for SOF samples from 7 modes of steady-state operation and from cold- and hot-start transient operation. In addition, BaP content was determined for background SOF derived from blank filter media and from used crankcase oil taken through the extraction process. Results from analysis for BaP are given in Table 31. Of the 7 modes tested, the idle condition produced the highest concentration of BaP. Relatively low concentrations of BaP were found for the 1600 rpm conditions and none were detected for the 2200 rpm conditions. The 7-mode composite was 0.058 μg BaP/kW-hr based on engine-derived SOF. Similar to steady-state results, transient operation also produced very low levels of BaP with a transient composite of 0.027 μg BaP/kW-hr based on engine-derived SOF. No BaP above the minimum detectable level was noted for the SOF derived from the blank filter media, and only a minimal concentration was noted for the SOF from the used crankcase oil.

e. Ames Response

The Ames test, as employed in this program, refers to a bacterial mutagenesis plate assay with Salmonella typhimurium according to the method of Ames.(15) This bioassay determines the ability of chemical compounds or mixtures to cause mutation of DNA in the bacteria, positive results occurring when histidine-dependent strains of bacteria revert (or are mutated) genetically to forms which can synthesize histidine on their own. Samples of the soluble organic fraction, representing a transient composite, were submitted for bioassay using five tester strains (TA1535,

TABLE 31. SUMMARY OF BENZO(a)PYRENE EMISSIONS FROM OPERATION OF THE M.A.N. D2566 FMUH METHANOL ENGINE

Steady-State Operation

Test Condition rpm/load	Benzo(a)pyrene Emissions			
	µg BaP/ mg SOF(Total)	µg BaP/ mg SOF(Engine)[a]	µg BaP/ kW-hr(Engine)[a]	µg BaP/ kg fuel(Engine)[a]
1600/2	0.0006	0.0006	0.16	0.025
1600/50	0.0007	0.0008	0.005	0.0096
1600/100	0.0014	0.0021	0.002	0.0038
Idle	0.0120	0.0180	--	0.074
2200/100	<0.0002	<0.0002	<0.0008	<0.0015
2200/50	<0.0002	<0.0002	<0.004	<0.0061
2200/2	<0.0002	<0.0002	<0.17	<0.022
7-mode Composite	0.0027	0.0041	0.058	0.090

Transient Operation

Cycle Type	Benzo(a)pyrene Emissions			
	µg BaP/ mg SOF(Total)	µg BaP/ mg SOF(Engine)[a]	µg BaP/ kW-hr(Engine)[a]	µg BaP/ kg fuel(Engine)[a]
Cold Start	0.0005	0.0006	0.028	0.037
Hot Start	0.0006	0.0006	0.027	0.039
Composite	0.0006	0.0006	0.027	0.038

Note: Extract from a blank filter was analyzed and indicated <0.0002 which was the minimum detectable level. In addition, extraction and analyses of used crankcase oil indicated a BaP concentration of 0.0003 µg/mg of SOF.

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[a] Computed on the basis of SOF contribution by the engine, whereas "(Total)" includes background extractables.

TA1537, TA1538, TA98 and TA100). Individual samples of seven steady-state modes of operation were submitted for bioassay with tester strain TA98.

All five strains are histidine-dependent cells by virtue of mutations within the histidine functional genetic unit. When these histidine-dependent cells are grown on minimal medium agar plates containing a limited amount of histidine, only those cells that revert to histidine independence are able to form colonies. The trace amount of histidine allows all the bacteria plates to undergo a few divisions, which is essential for mutagenesis to occur. It is these histidine-independent revertants which are scored as colonies against a slight background growth consisting of histidine-requiring cells that have depleted the histidine present within the minimal medium.

In addition to mutations in the histidine-functional genetic unit, all the tester strains have a defective lipopolysaccharide coat which allows large molecules to permeate the bacterial wall, thus increasing bacterial sensitivity to mutagenic aromatic compounds. Furthermore, a U.V. mutation decreases bacterial sensitivity to additional mutagenic agents. TA1535 and its plasmid-containing counterpart, TA100, detect base pair substitutions, while TA1537 (and TA1538 with its plasmid-containing counterpart, TA98) respond to frameshift mutagens. The plasmids present in TA98 and TA100 are believed to cause an increase in error-prone DNA repair which leads to many more mutations. Thus, the five tester strains in tandem provide a very sensitive method for the detection of potential mutagenic environmental samples.

Results given in Tables 32 and 33 include the slope of dose response, which represents the statistically determined slope of the function representing revertants per plate versus microgram SOF dosage. This result is termed "specific activity", and is an indication of the level of mutagenic potential of the extract. A "brake specific response" was computed by applying the specific activity to the brake specific emission of SOF. This results in a term with units of "revertants per plate per kW-hr" which is useful for comparison purpose, but which has no practical meaning.

From the steady-state results given in Table 32, there was little difference in the specific activity obtained with the TA98 between tests with and without metabolic activation. Comparing specific activities, the most bioactive SOF originated during full load operation, activity decreasing with decreasing load. Seven-mode composites of these activities were 0.84 and 0.95x10^6 rev/g SOF with and without metabolic activiation, respectively. When these specific activities are combined with the SOF emission rates for the various modes of operation, the highest "specific rate" was obtained for maximum power operation, and the rate generally decreased with decreasing power output. The computed 7-mode composite specific rates, with and without metabolic activation, were 0.43 and 0.47x10^6 rev/hr, respectively. Using the 7-mode composite power level of 54.3 kW, the brake specific responses were 0.0079 and 0.0087x10^6 rev/kW-hr with and without metabolic activation, respectively.

TABLE 32. SUMMARY OF AMES RESPONSE TO MODAL SAMPLES OF SOF FROM THE M.A.N. METHANOL ENGINE WITH STRAIN TA98 (WITH AND WITHOUT METABOLIC ACTIVATION)

Sample Test Condition rpm/% load	Total Part. Rate g/hr	SOF Rate g/hr	Metabolic Activation Status	Specific Activity 10^6 rev/g SOF	Specific Rate 10^6 rev/hr
1600/2	0.79	0.64	No	0.1	0.06
			Yes	0.1	0.06
1600/50	0.86	0.41	No	0.6	0.25
			Yes	1.0	0.41
1600/100	0.83	0.11	No	2.3	0.25
			Yes	1.4	0.15
Idle	0.041	0.017	No	0.1	0.002
			Yes	0.2	0.003
2100/100	1.9	0.57	No	3.8	2.1
			Yes	3.2	1.8
2100/50	2.1	1.4	No	0.5	0.70
			Yes	0.4	0.56
2100/2	3.4	2.7	No	0.1	0.27
			Yes	0.1	0.27

TABLE 33. SUMMARY OF AMES RESPONSE TO TRANSIENT COMPOSITE OF SOF FROM THE M.A.N. METHANOL ENGINE (WITH AND WITHOUT METABOLIC ACTIVATION)

Ames Test Strain	Metabolic Activation Status	Specific Activity 10^6 rev/g SOF	Brake Specific Response 10^6 rev/kW-hr
TA98	No	0.4	0.02
	Yes	0.7	0.04
TA100	No	0.8	0.05
	Yes	0.5	0.03
TA1535	No	0.0	0.00
	Yes	0.0	0.00
TA1537	No	0.1	0.01
	Yes	0.1	0.01
TA1538	No	0.4	0.02
	Yes	0.5	0.03

Results for the submitted composite SOF sample, consisting of 1/7 cold- and 6/7 hot-start transient SOF, on all five tester strains for bioactivity are given in Table 33. For TA98, the bioactivity of the composite transient SOF was increased with metabolic activation. The average specific activity of the transient composite for tester strain TA98 was near that of the 7-mode composite of specific activity (0.6 vs 0.9). Of the 5 tester strains used, TA98, TA100 and TA1538 all had similar dose responses. No response was noted for strain TA1535. Since the same brake specific composite transient emission of SOF (0.061 g SOF/kW-hr) was applied, the trends noted for specific activity also apply to the brake specific response. The average of the brake specific responses over all five tester strains resulted in 0.021×10^6 rev/kW-hr. This is significantly higher than those obtained for the 7-mode composite, which averaged 0.008×10^6 rev/kW-hr (including tests with and without metabolic activation); and may indicate that substantially more bioactive species are emitted during speed and load transition periods over transient testing than are emitted in steady-state testing at various load conditions. Ames response to used engine oil carried through the SOF extraction process showed no bioactivity using tester strain TA98. In addition, no correlation between modal BaP levels given in Table 31 and modal Ames response given in Table 32 was noted.

V. EMISSION COMPARISON TO OTHER ENGINES

This section is intended to compare the emissions from the M.A.N. D2566 FMUH methanol engine to emission results from the dual-fuel Volvo TD-100A engine and a similar diesel Volvo TD-100C engine characterized under Task Specification No. 6 of EPA Contract No. 68-03-2884. Although the dual-fuel Volvo engine was characterized over 5 configurations including methanol, methanol with catalyst, ethanol, ethanol with catalyst and ethanol with 30 percent water, only the methanol configurations will be compared here. Both the M.A.N. and the Volvo alternate-fuel engines can utilize fuels derived from a non-petroleum base. Many schemes have been developed which are capable of producing power from alternate fuels, with a variety of success and problems.

The M.A.N. engine uses spark ignition, whereas the Volvo dual-fueled engine uses pilot injection of diesel fuel to initiate the combustion of methanol. In this discussion, to distinguish between the two direct-injected engines, the M.A.N. engine will be designated as spark-ignited and the Volvo dual-fuel engine designated as pilot-injected. Both the Volvo dual-fuel engine and its diesel counterpart are described in detail in the Final Report, EPA 460/3-81-023, "Emission Characterization of an Alcohol/Diesel-Pilot Fueled Compression-Ignition Engine and Its Heavy-Duty Diesel Counterpart."(4)

A. Regulated Emission Results

Thirteen-mode FTP emission levels of HC, CO and NO_x were determined for all three engines. Engine performance observed during the 13-mode testing is given below. The diesel engine and the spark-ignited methanol engine were tested as received.

Test Configuration	Torque N•m	Intermediate Speed, rpm	Max. Power kW	Rated Speed, rpm
Diesel	880	1400	179	2200
Pilot-Injected	958	1400	189	2200
Pilot-Inj.+Cat.	990	1400	191	2200
Spark-Ign.+Cat.	769	1600	142	2200

The pilot-injected engine was tested after a 5° timing retard of alcohol injection timing and adjustment of both diesel pilot and methanol injection rates to obtain 186 kW at 2200 rpm with minimum HC emissions.

Methods for computation of 13-mode emission from heavy-duty diesel engines are specified in the Federal Register.(5) Modifications to these emission computations had to be incorporated in order to account for the use of oxygen-containing fuel (methanol), complicated by the fact that the diesel pilot-injected engine consumed varying fractions of methanol and diesel fuel. Mass emissions were computed on the basis of measured and corrected concentrations of the emitted species, multiplied by the molecular weight of each pollutant and by the measured fuel, and divided by the carbon-containing emission concentrations and the molecular weight of the fuel. For the diesel pilot-injected engine, the molecular weight of the fuel ranged from 13.88 grams/mole per carbon atom (during idle and the 1400 rpm/2 percent load condition) to 28.77 grams/mole per carbon atom during maximum power operation, due to the relative mass portions of diesel and methanol used over the 13-mode procedure, illustrated in Figure 21. For the spark-ignited methanol-catalyst engine, a fuel molecular weight of 32.04 grams/mole per carbon atom was used.

Composite 13-mode emission levels for the diesel engine, the pilot-injected engine in both the methanol and methanol-catalyst configurations, and the spark-ignited methanol-catalyst engine are given in Table 34 along with BSFC on a measured fuel and diesel equivalent basis.(18)

TABLE 34. COMPARATIVE 13-MODE EMISSIONS FROM THREE ENGINES

Engine Configuration	Emission Rate, g/kW-hr HC	CO	NO_x[b]	BSFC kg/kW-hr	BSFC Diesel Equiv.
Diesel	1.05	3.18	11.88	0.262	0.262
Pilot-Injected	1.45[a]	9.55	5.26	0.486	0.289
Pilot-Inj.+Cat.	0.65[a]	0.83	6.79	0.482	0.287
Spark-Ign.+Cat.	0.24[a]	0.39	9.13	0.624	0.287

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[a] These mass emission values based on diesel-like HC species.
[b] NO_x correction factors for intake humidity were not applied.

The individual mode emission rates for HC, CO, and NO_x are illustrated in Figure 22 on a g/hr basis. The mass of hydrocarbons tabulated above assumed the exhaust HC species had a molecular weight of 13.88 and a HFID response factor of unity.

Compared to the diesel engine, 13-mode composite hydrocarbons from the pilot-injected configuration increased 38 percent with the substitution of methanol. Increases in hydrocarbons were most significant during the 2200 rpm/25, 50, and 75 percent load conditions where hydrocarbons more than doubled. The addition of the catalyst significantly reduced total hydrocarbons for both pilot-injected and spark-ignited methanol engines. Further discussion of total hydrocarbon emissions will be given after other hydrocarbon-related emissions have been discussed.

Thirteen-mode composite CO emissions were higher by a factor of 3 for the pilot-injected methanol engine, relative to the diesel engine. Levels of CO were extremely high during the 1400 rpm/75 and 100 percent load

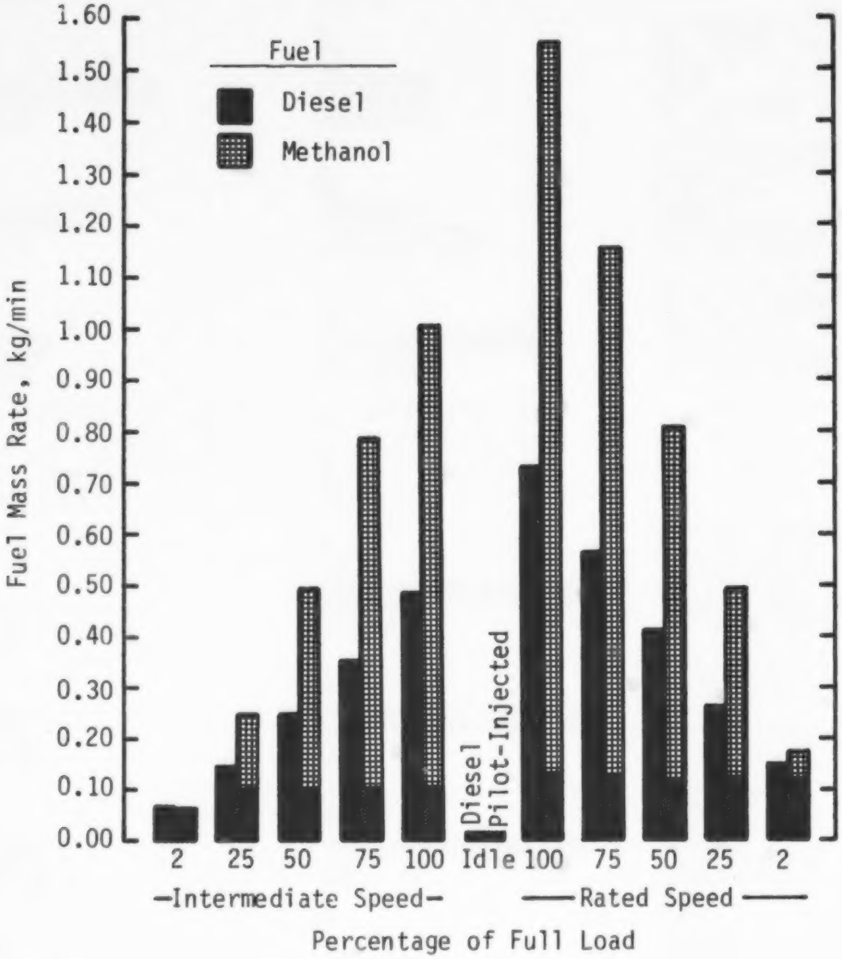

Figure 21. Fueling schedules for the diesel and pilot-injected engines over 13-mode testing

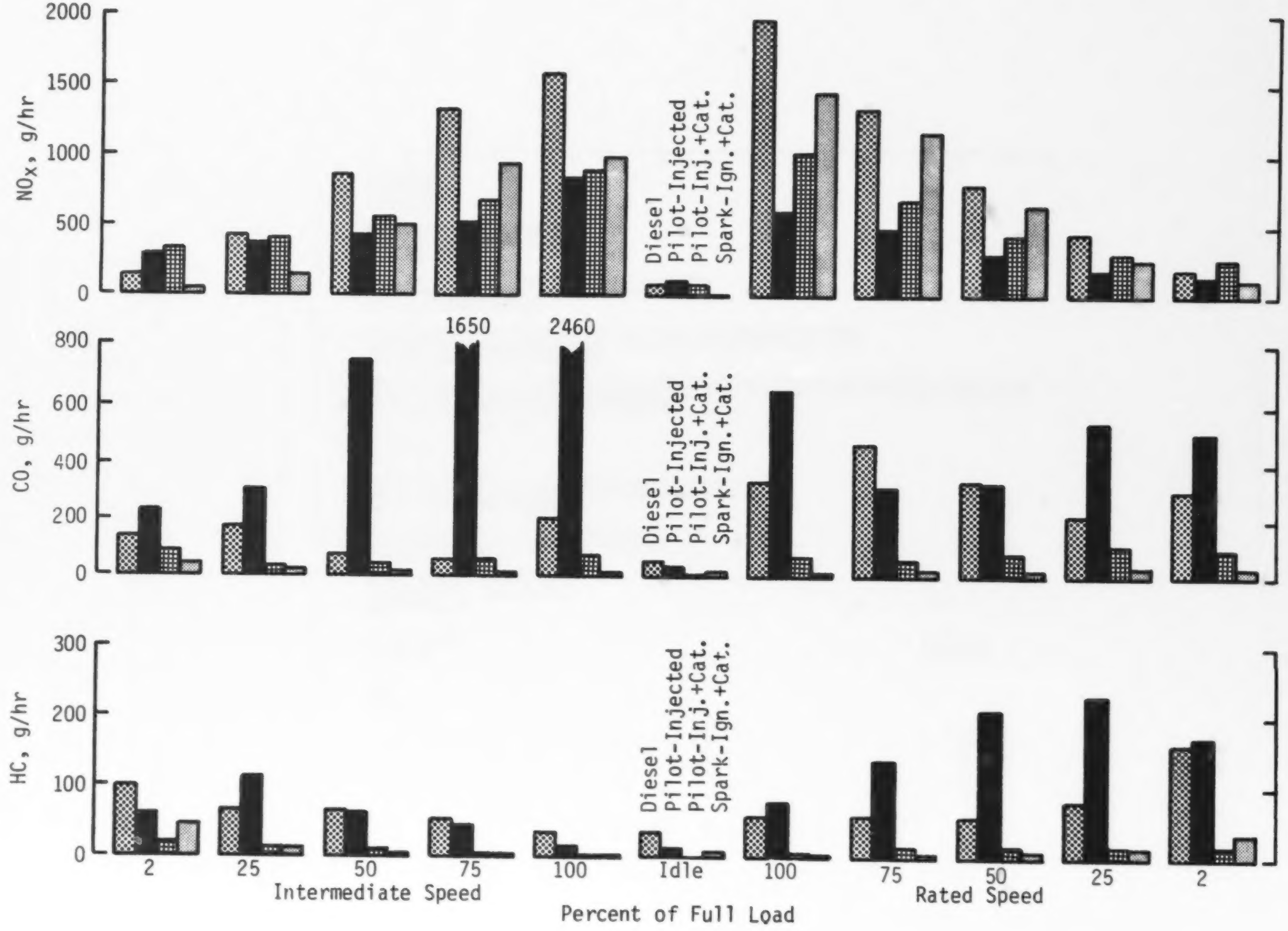

Figure 22. Mass emissions over the 13-mode procedure from the diesel, pilot-injected, pilot-injected with catalyst, and spark-ignited with catalyst engines

conditions. The catalyst reduced CO emissions from both the pilot-injected and spark-ignited engines to 26 and 12 percent of the diesel engine levels, respectively.

CO levels from the pilot-injected methanol engine were also measured by Volvo and Statens Naturvardsverks Bilagaslaboratorium (SNV) prior to testing by SwRI and indicated significantly lower CO levels (1/2 to 1/5) during 1400 rpm/50, 75 and 100 percent load conditions. There were several differences between testing this engine at SwRI and Volvo or SNV. Alcohol injection was retarded 5°, 25 percent more pilot diesel injection was used, and 12 percent lower cetane diesel fuel (44) was used at SwRI. In addition, SwRI used heated sample lines (190°C) according to diesel practice and a dry ice-isopropyl alsohol water trap was used in the CO, CO_2, and NO_x sample trains.(19)

Since completion of the program, Volvo has asserted that a possible reason for the high CO levels was the dissociation of methanol into H_2 and CO at temperature and pressure conditions similar to those which may have occurred in the exhaust pipe or even the heated sample line.(20) Volvo referenced D.L. Hagen's work which showed that a great amount of methanol will dissociate to CO and H_2 at low pressure and high temperature. In fact, Hagen indicates 100 percent dissociation at 1 atmosphere and 200°C.(21)

If dissociation does occur, it is likely that it would reach equilibrium within the higher temperature exhaust stream and would not be increased by use of the heated sample line maintained at 190°C (375°F). Even the remote possibility of distorting the various emissions levels by use of a heated sample train is disturbing and some qualification experiments may be needed to insure accurate determinations of CO, total hydrocarbons, unburned methanol and aldehydes when methanol fuel is used.

The sample train used for both CO and CO_2 showed evidence that all the water was not trapped within the ice bath water trap used during the 13-mode procedure when the pilot-injected methanol engine was run. To remove additional water, dry ice (CO_2) and isopropyl alcohol were used to lower the temperature to near -76°C (-105°F). This system (normally used by SwRI for the NO_x sample train) only removed about 0.7 percent more water vapor on a volume basis than ideally taken out by the 2°C ice bath water trap for normal diesel tests.(19) Besides reducing the volumetric contributions of water vapor, use of the -76°C dry ice trap may have caused some interference to NDIR-determined CO emissions, and may have contributed to higher measured concentrations.

Composite NO_x emission from the pilot-injected methanol configuration was 56 percent lower than from the diesel engine. A portion of this reduction was due to a 5 degree retard of alcohol injection from 24° BTDC to 19° BTDC, which yielded lower NO_x emissions but higher fuel consumption. The addition of the catalyst to the pilot-injected engine appeared to cause a 29 percent increase in NO_x. Since it it not likely that the oxidation catalyst increased in the NO_x formation, perhaps the catalyst eliminated an unknown measurement interference present during testing without the catalyst. Unburned alcohols are one possibility, because alcohols decreased when the catalyst was added to the pilot-injected engine in the same modes where NO_x levels were higher (See Figure 22). Volvo reported 8.10 and 8.59 grams NO_x per kW for this engine, with and without catalyst, respectively. Besides the differences already noted above, the higher NO_x obtained with the catalyst added is puzzling, and more work is needed.

The 13-mode composite NO_x emissions from the spark-ignited methanol-catalyst engine were also somewhat higher than expected, and significantly higher than those reported by M.A.N. (58 percent). In addition to some of the sample train differences noted above, M.A.N. determined "NO_x" measuring NO by NDIR, without an NO_x to NO converter. A reason for the significant difference may be substantial variation of NO to NO_2 concentration ratios found with use of methanol as a fuel. The ratio of NO_2 to NO has been shown by Heisey and Lestz(22) to range from 0.04 to 3.6 when using from 0 to 30 percent methanol fumigation into a single cylinder diesel. The higher NO_x levels reported here may be due to differences in instrumentation, sample handling, and ambient test conditions.

Brake specific fuel consumption over the 13-mode test was based on measured fuel quantities. As shown in the 13-mode emission tabulation, the BSFC is substantially higher with methanol, as expected. For comparative purposes, the dual-fueled and methanol fuel BSFC's were converted to diesel fuel (19.7 and 42.8 MJ/kg, respectively).(18) On the basis of diesel equivalent, the pilot-injected engine showed a 10 percent increase in BSFC compared to the diesel engine. This result is partially due to testing at 19° BTDC timing for lower NO_x rather than at 24° BTDC timing for best fuel consumption. The diesel equivalent BSFC from the naturally-aspirated spark-ignited methanol engine was the same as for the turbocharged pilot-ignited engine.

Transient FTP emissions levels of HC, CO and NO_x were also determined for all three engines. Figure 23 illustrates the results of the transient mapping used to generate the transient command cycle. The dips in the torque curves between 600 and 1000 rpm reflect driveline vibration interferences with torque measurement. The torque maps from the diesel and pilot-injected engine are similar in shape, but the torque map from the spark-ignited methanol catalyst engine shows relatively higher torques at low engine speeds due to high rates of fueling during low speed operation. Some of the results from these maps are tabulated below. The resultant transient command cycle work values were 11.68, 12.39, and 9.14 kW-hr for the diesel, pilot-injected and spark-ignited engine, respectively.

Engine Configuration	Max. Map Torque, N•m	Engine Speed, rpm	Max. Map Power, kW	Engine Speed, rpm
Diesel	881	1600	181.3	2300
Pilot-Injected	988	1500	185.8	2200
Spark-Ign.+Cat.	796	800	135.8	2000

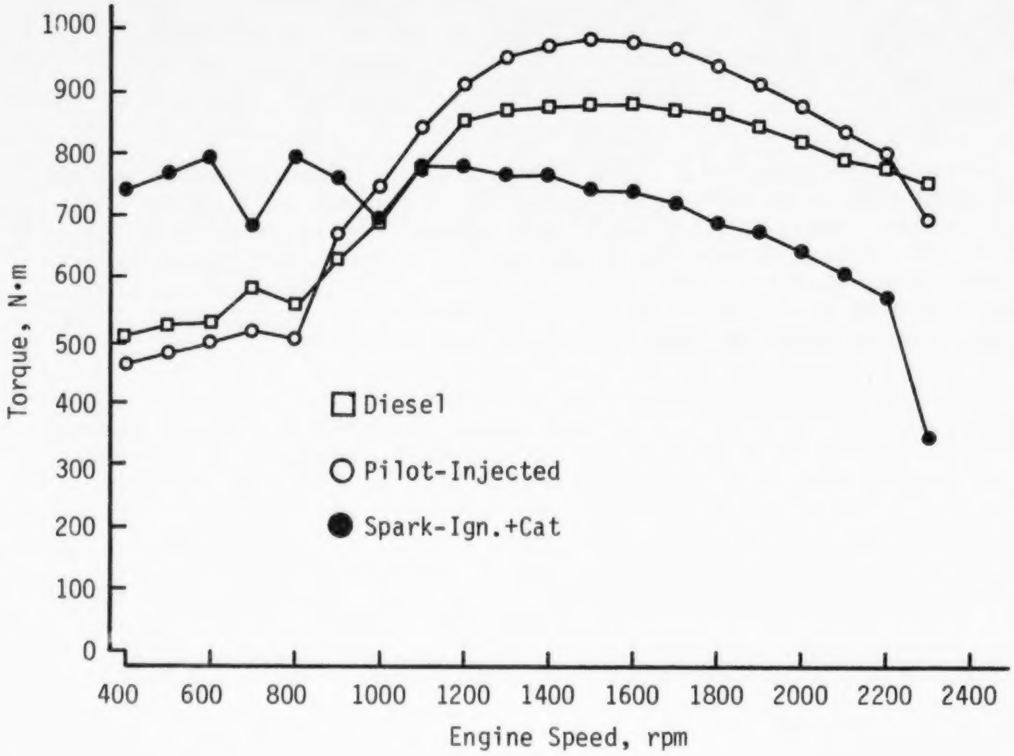

Figure 23. Transient torque map from the diesel and two methanol-fueled engines

Composite emissions from cold- and hot-start transient cycle testing are given in Table 35. In addition, the cold- and hot-start levels of these emissions are shown in Figure 24 along with corresponding 13-mode composite levels. All of the transient HC mass emissions were computed using an exhaust HC density of 0.5768 kg/m^3 (16.33 g/ft^3) on the basis of diesel fuel-like HC species.

TABLE 35. COMPARATIVE TRANSIENT FTP EMISSIONS

Engine Configuration	Emission Rate, g/kW-hr HC	CO	NO_x	BSFC kg/kW-hr	BSFC Diesel Equiv.
Diesel	1.15	4.04	11.19	0.288	0.288
Pilot-Injected	1.95	10.29	7.31	0.531	0.297
Pilot-Inj.+Cat.	0.16	3.61	7.39	0.518	0.295
Spark-Ign.+Cat.	0.06	0.42	8.86	0.708	0.326

Methanol and diesel fuel used in the pilot-injected methanol configuration increased total HFID hydrocarbons by 70 percent relative to the diesel engine. Addition of the catalyst reduced the level of HC by 92 percent. HC emissions from the spark-ignited methanol-catalyst engine were even lower than from the pilot-injected methanol-catalyst configuration. As with the 13-mode data, further discussion is presented after individual hydrocarbon and aldehydes data are presented.

Brake specific CO emissions over the transient cycle were 2.6 times higher for the pilot-injected methanol engine than for the diesel engine, and compare well with the trend noted for 13-mode composite CO emissions. Both CO and CO_2 were taken from a dilute sample bag using an unheated sample train. Application of the catalyst to the pilot-injected engine reduced transient composite CO by 65 percent. This reduction was not as significant as for the 13-mode test, likely due to much lower catalyst temperatures during transient testing than over the steady-state testing. Transient CO emissions from the spark-ignited methanol-catalyst engine were 88 percent lower than for the pilot-injected methanol-catalyst engine and were about the same as the 13-mode level. One possible explanation for this difference is that the catalyst was more active or more efficient for the spark-ignited engine. This could be due to factors such as higher operating temperatures or differences in catalyst formulation.

The NO_x emissions from the pilot-injected engine over the transient test (where dilute exhaust is sampled from a constant volume system) were 35 percent below the diesel engine NO_x levels. Both the pilot-injected engine and the spark-ignited engine had similar NO_x levels during the transient testing when sampling from CVS dilute exhaust. This finding appears to disagree with the variation in 13-mode NO_x reported for the pilot-injected engine, and may indicate that a chemiluminescence (CL) instrument interference occurred while sampling raw exhaust from the

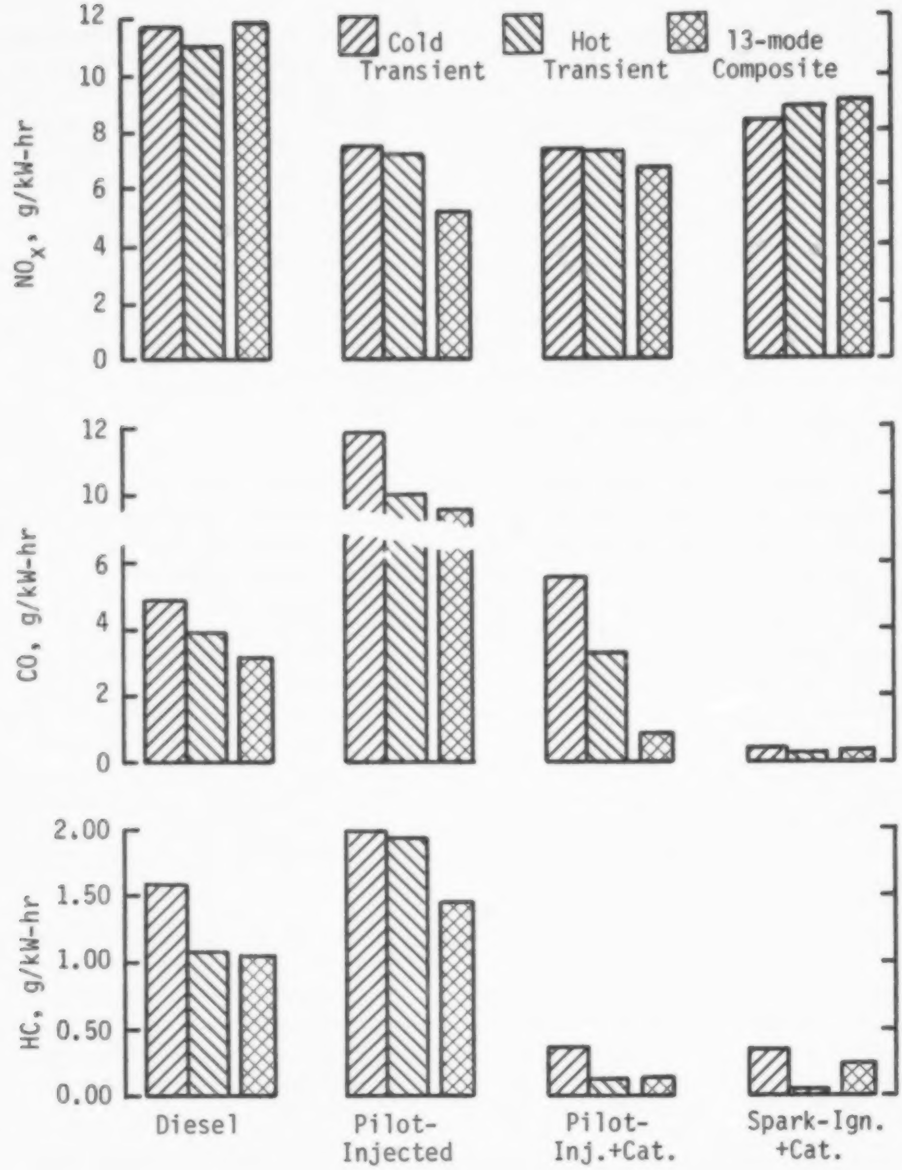

Figure 24. Brake specific emissions from the diesel and methanol-fueled engines

pilot-injected configuration. NO_x emissions over the transient test cycle from the spark-ignited engine were 20 percent higher than those from the pilot-injected engine, and show the same trend noted for the 13-mode emissions.

BSFC over the transient test increased with the use of methanol fuel, as expected on the basis of 13-mode results. Approximately 80 percent of the fuel mass consumed over the transient cycle by the pilot-injected engine was methanol, even though no methanol was used during idle and light loads. The pilot-injected BSFC's were computed on the basis of carbon balance, using measured fuel quantities to establish a percent fuel carbon value. The transient BSFC (diesel fuel equivalent) over the transient cycle for the pilot-injected engine was 2.8 percent higher than for the diesel engine. The BSFC over the transient cycle for the spark-ignited engine was highest of the three, likely due to the higher fueling schedule at relatively low speeds as compared to the diesel and pilot-injected engines. The fueling schedule of the spark-ignited engine was optimized for use with an automatic transmission.

B. Unregulated Emission Results

Determination of unburned alcohol is important from the standpoint of total hydrocarbon emissions when consuming methanol. Figures 25 and 26 show the relative unburned methanol emission rates obtained for both methanol-fueled engines over 7-modes and cold- and hot-start transient operations. Seven-mode composite brake specific rates are also given in Figure 26. Most of the unburned methanol from the pilot-injected methanol configuration was noted during 2200 rpm modes, especially at 50 percent load. Over the transient cycle, both cold- and hot-start sequences showed similar levels of unburned methanol at about twice the 7-mode composite level. Addition of the catalyst caused substantial reductions in unburned methanol over most of the modes in which the catalyst temperatures were relatively high, reducing the 7-mode composite by 57 percent. Transient unburned methanol was reduced 82 percent by the catalyst. Over the transient cycle, the catalyst used with the pilot-injected engine reached 200°C after about 450 seconds.

Unburned methanol levels from the spark-ignited methanol-catalyst engine were relatively high during the light loads and zero during the high load conditions, resulting in a 44 percent lower level of 7-mode composite unburned methanol than found with the pilot-injected methanol-catalyst engine. Even though the catalyst reached 200°C within 60 seconds of cold or hot transient start-up, unburned methanol was 2.4 times higher for the cold-start than for the hot-start transient.

From the standpoint of potential health effects, the measurement of formaldehyde emission when using methanol is considered very important due its high photochmeical reactivity, potential carcinogenicity and eye irritation qualities. Figures 27 and 28 show the emission rates of aldehydes obtained from steady-state and transient operation of the three engines.

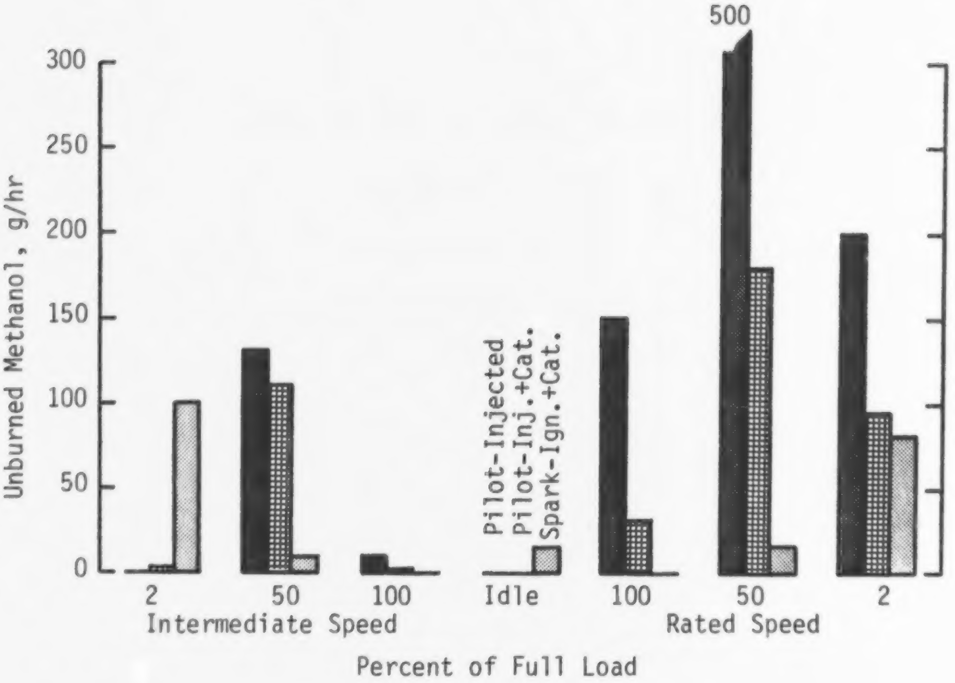

Figure 25. Unburned methanol emissions over 7-mode cycle for methanol-fueled engines

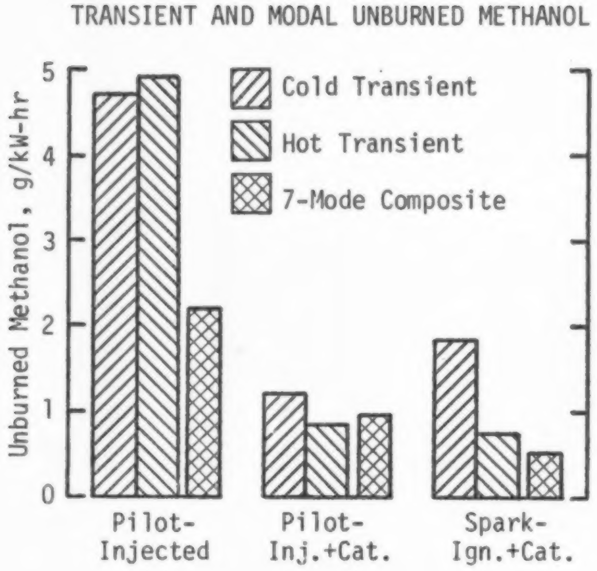

Figure 26. Brake specific methanol emissions from the methanol-fueled engines

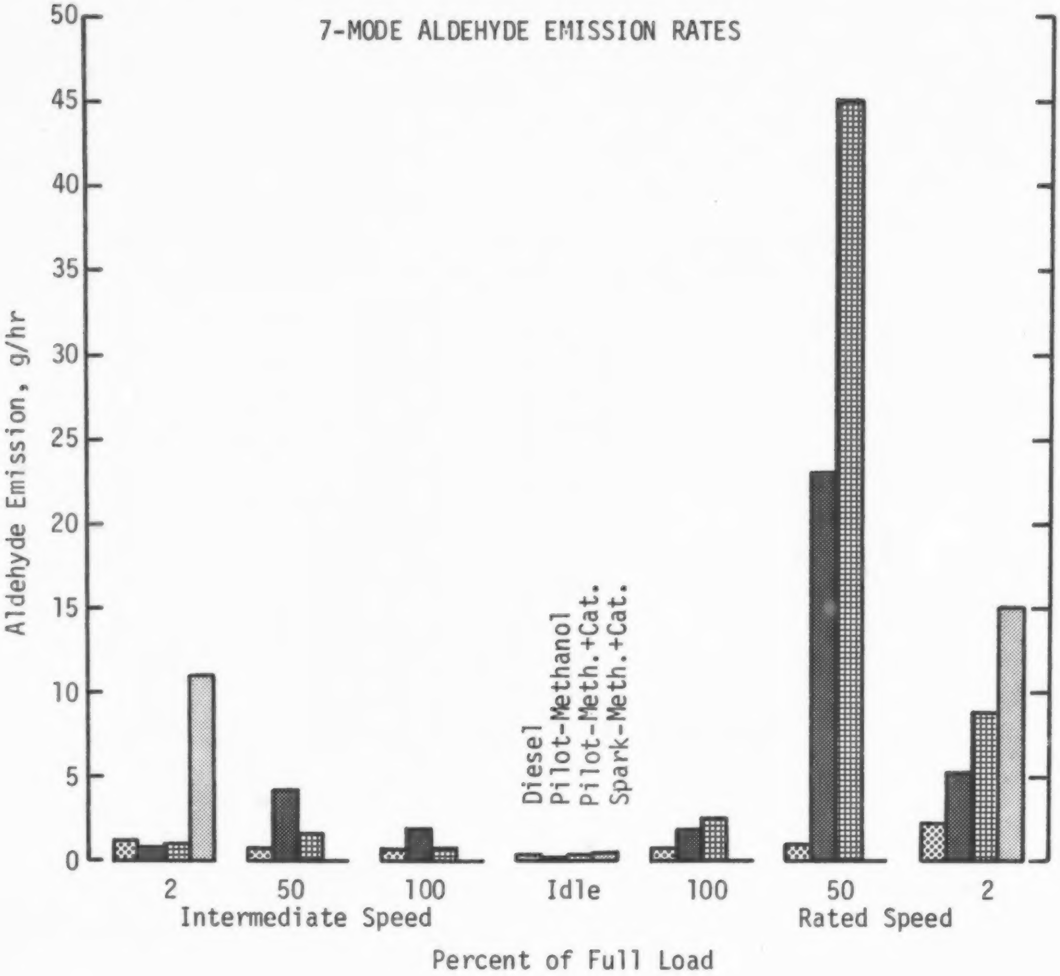

Figure 27. Seven-mode aldehyde emissions from the diesel and methanol-fueled engines

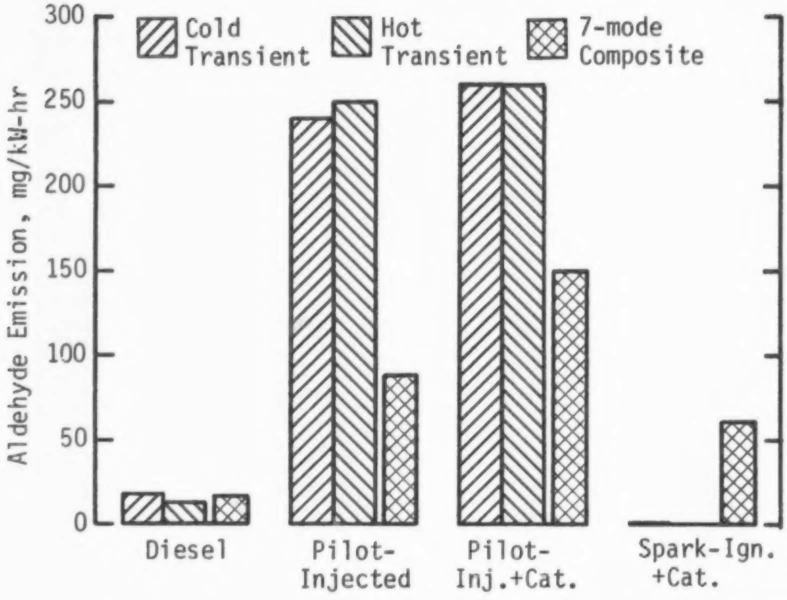

Figure 28. Brake specific aldehyde emissions from the diesel and methanol-fueled engines

The diesel engine generally showed low (typical for a diesel) emissions of formaldehyde along with small quantities of acetaldehyde and hexanaldehyde.(8) The pilot-injected methanol configuration showed much higher formaldehyde emissions, particularly during 1400 rpm/50 percent load and 2200 rpm/50 and 2 percent load conditions. Over the transient test, the aldehydes (mostly formaldehyde) increased to about 14 times that of the diesel level, while the 7-mode composite emissions were higher by a factor of 4.6.

Addition of the catalyst to the pilot-injected engine reduced aldehydes over the intermediate speed range, but actually increased aldehyde emissions during rated speed steady-state operation. The 7-mode composite of aldehydes showed a 97 percent increase with catalyst. It appears that the catalyst was not efficient enough to oxidize the relatively large quantities of unburned methanol during 2200 rpm/2 and 50 percent load conditions, and instead may have partially oxidized the methanol to formaldehyde. Aldehydes were also higher during transient operation with the catalyst possibly due to catalytic reduction at some conditions being offset by others where the catalyst was unable to fully oxidize the formaldehyde or unburned methanol.

Aldehyde levels from the spark-ignited methanol-catalyst engine were extremely low during the higher-loaded steady-state modes, but were significant during prolonged 2 percent load conditions when exhaust temperature was relatively low and unburned methanol was high. Results from aldehyde measurements taken with a partially-failed catalyst showed aldehyde emission rates of 8 g/hr for the idle condition, 35 g/hr for the 1600 rpm/2 percent load condition and 44 g/hr for the 2200 rpm/2 percent load condition. These results illustrate that a too small or defective catalyst can significantly increase formaldehyde levels. Aldehyde measurements over the transient cycle indicated no aldehydes from the spark-ignited engine. A raw, non-proportional sample was taken, and it indicated very low levels over the cold-start cycle. Since the catalyst used with the spark-ignited engine warms up quickly and appears to be quite efficient, the cold-start aldehydes are likely formed only during the relatively short time period required for catalyst light-off, where the catalyst is only partially active.

Results from measurement of selected individual hydrocarbons (IHC) from the diesel engine showed primarily ethylene over 7 modes of steady-state operation, with methane, acetylene, and propylene found during idle and the 2 percent load conditions. These compounds were also noted in transient operation, primarily over the cold-start cycle. Only methane and ethylene were noted during the hot-start. The 7-mode and transient composites for the diesel engine were 120 and 130 mg/kW-hr, respectively. For the pilot-injected methanol engine, all of these four species were reduced at light loads, during which only diesel fuel was injected. These individual hydrocarbons were higher during full load conditions, resulting in a 7-mode composite of 67 mg/kW-hr. The transient composite for this engine configuration was 180 mg/kW-hr, 38 percent greater than the diesel engine IHC. Over 7-modes, the addition of the catalyst reduced the composite to 32 mg/kW-hr. This decrease was due to reduction of ethylene and elimination of acetylene and propylene, even though methane levels increased. Measurement of IHC emissions from the spark-ignited engine showed no methane above background levels and only a trace of ethylene, resulting in a 7-mode composite level of 0 mg/kW-hr. Only a trace of methane was noted during the cold-start, giving a composite value of 1.1 mg/kW-hr for transient operation.

Over the transient cycle, phenol emissions of 35mg/kW-hr were measured for the diesel engine as compared to 24 mg/kW-hr for the pilot-injected methanol configuration. Use of the catalyst with this engine increased phenols over the transient cycle to 48 mg/kW-hr. For both pilot-injected configurations, the phenols measured were generally of the more highly substituted species having higher molecular weights. No phenols were detected over transient operation of the spark-ignited methanol-catalyst engine. This result may be attributed to a more active catalyst or perhaps the absence of diesel fuel. Determinations of the total intensity of aroma (TIA) by the DOAS procedure, which measures oxygenate and aromatic fraction of exhaust gases, is related to other hydrocarbon analysis. In comparison to the diesel engine, TIA values were generally lower with methanol, and the oxidation catalysts on both the pilot-injected and spark-ignited engines, yielded even lower levels of TIA.

FID responses to the different HC species found in the exhaust are quite variable, and range from an estimated 0.05 for formaldehyde to 1.0 for species measured by the IHC and phenols procedures.(9) Methanol has been shown to have an HFID response of about 0.8.(20) The total hydrocarbons from 13-mode and transient testing were reported earlier on the basis that the HC exhaust species were similar to diesel fuel-like species. The "actual" total hydrocarbons for the engines may be determined by summing up the results from the various specialized procedures used to determine unburned methanol, aldehydes, IHC and phenols. The results of this are illustrated in Figure 29 and presented in Table 36.

TABLE 36. COMPARATIVE TOTALS OF MEASURED HYDROCARBONS

Engine Configuration	Actual Total Hydrocarbons, g/kW-hr	
	7-Mode	Transient
Diesel	1.07[a]	1.16
Pilot-Injected	2.37	5.33
Pilot-Inj.+Cat.	1.14	1.26
Pilot-Ign.+Cat.	0.59	0.91

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[a] 13-mode + 7-mode aldehyde

Based on these actual measured hydrocarbons, methanol substitution in the pilot-injected engine increased both steady-state and transient hydrocarbon mass emissions to 2.2 and 4.6 times those of the diesel engine. The addition of the catalyst reduced the hydrocarbons to near the level obtained

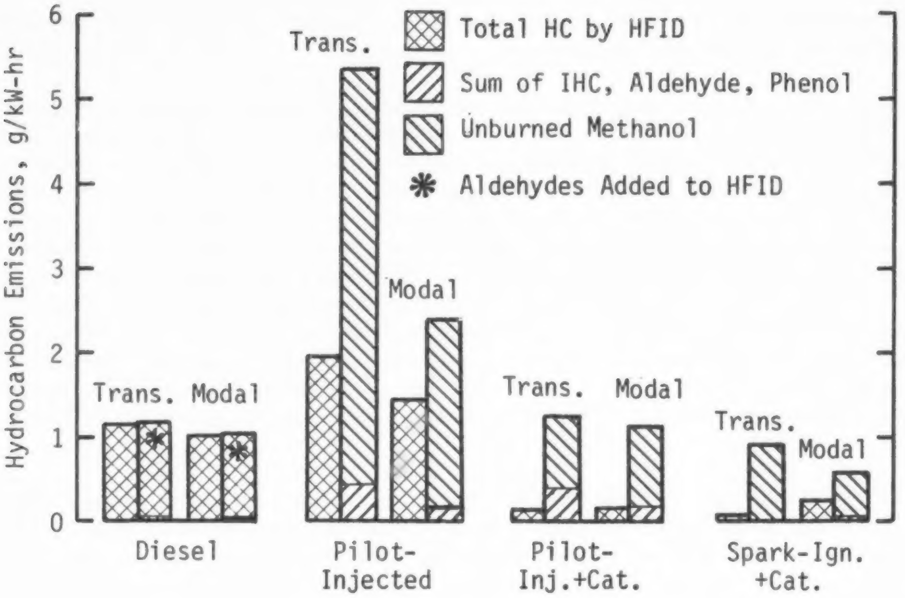

Figure 29. Brake specific total hydrocarbons by HFID and by summation of various HC analyses

from the diesel engine. Actual total hydrocarbon emissions from the spark-ignited engine were still quite low, but not nearly as low as indicated by the total hydrocarbons calculated on the basis of diesel fuel.

C. Particulate Emission Results

Total particulate results from modal testing are given in Figure 30 while transient results and 7-mode composite particulate rates are presented in Figure 31. Particulate emissions from the diesel engine were generally low during low power conditions, increasing substantially with load. Use of methanol in the pilot-injected engine reduced maximum torque and maximum power particulate by 86 to 92 percent, respectively. Despite substantial increases in total particulate noted during 2 percent load condition, where mostly pilot diesel fuel is consumed, both the 7-mode and transient particulate emissions were reduced by 57 and 44 percent, relative to the diesel engine.

Addition of the catalyst to the pilot-injected methanol engine substantially increased the total particulate during the high-load, high-temperature steady-state operating conditions, but significantly reduced particulate during idle and the 2 percent load conditions. The 7-mode composite increased from 0.30 to 0.50 g/kW-hr when the catalyst was added. Over transient testing both cold- and hot-start particulate were lower with the catalyst than without. Particulate rates from the spark-ignited engine were extremely low over both steady-state and transient operation relative to any configuration tested. No carbon (soot) particulate was visible on any of the filters obtained from the spark-ignited methanol catalyst engine. The transient composite particulate was 0.06 g/kW-hr which is well below the proposed 1986 limit of 0.34 g/kW-hr (0.25 g/hp-hr).

"A", "b", and "c" factors of the FTP smoke procedure were reduced by 61, 90, and 30 percent of the diesel engine levels when the pilot-injected engine was operated on methanol. The addition of the catalyst reduced the "a" and "c" factors even further. Results from FTP smoke testing of the spark-ignited engine indicated zero smoke opacity for all three factors.

The relative contributions of sulfate to both steady-state and transient operation are indicated in Figures 30 and 31. Analysis of the total particulate for sulfate indicated normal amounts of fuel sulfur conversion to sulfate for the diesel engine over seven steady-state modes. Of the 7-mode composite total particulate (0.69 g/kW-hr), 6.5 percent was sulfate. The sulfate rates from both steady-state and transient operation decreased significantly with methanol substitution in the pilot-injected engine. However, the addition of the catalyst to the pilot-injected engine increased the particulate levels dramatically when catalyst temperature was sufficient to convert sulfur dioxide in the exhaust (originally from combustion of sulfur in the pilot diesel fuel) to sulfate. Sulfate accounted for 43 and 27 percent of the 7-mode and transient composite particulate levels reported for the pilot-injected methanol catalyst configuration, respectively. It was assumed that the spark-ignited engine generated no sulfate emissions, since the only source of sulfur would be minute amounts of crankcase oil consumed.

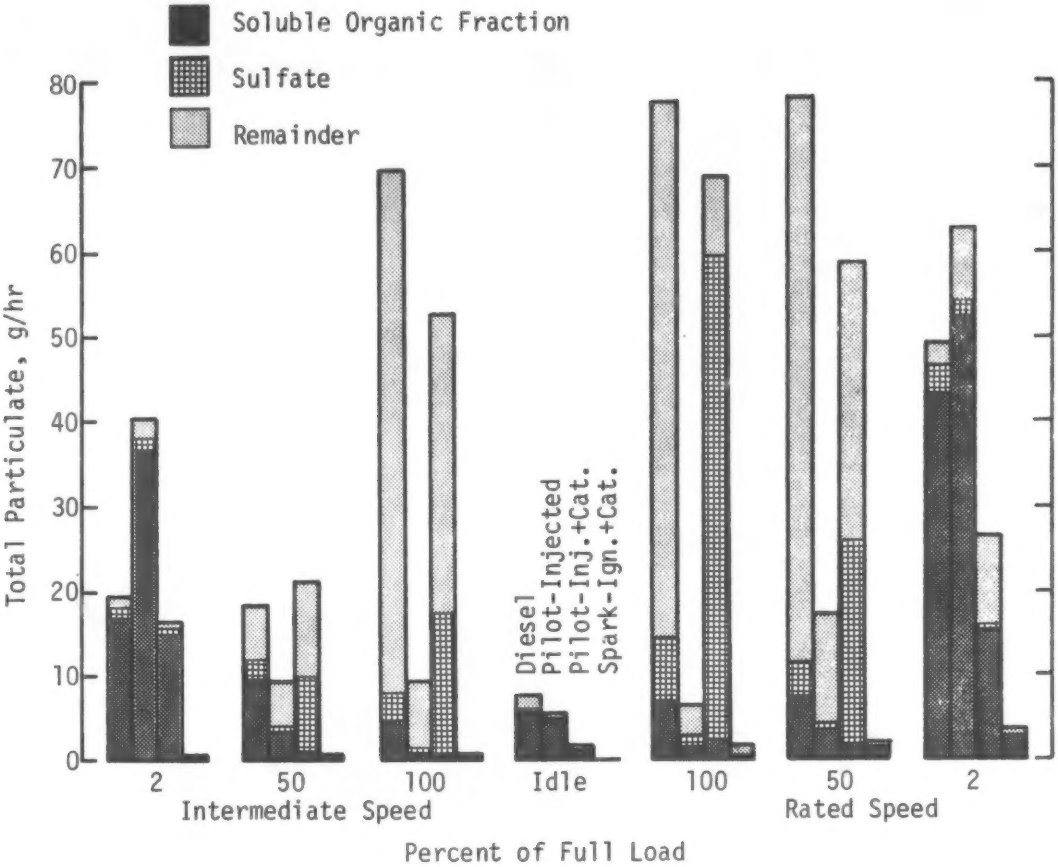

Figure 30. Total particulate from 7 modes of steady-state operation

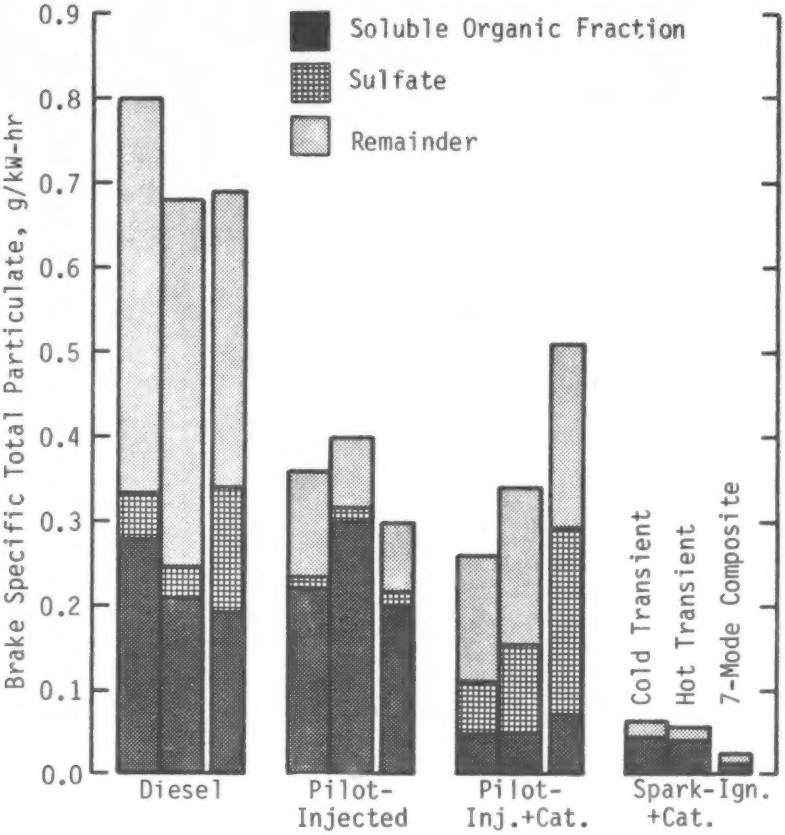

Figure 31. Brake specific total particulate from the diesel and methanol-fueled engines

Another major contribution to total particulate was the soluble organic fraction (SOF), which is also indicated in Figures 26 and 27. As with most diesel engines, most of the 7-mode composite SOF was generated during the light load conditions where f/a ratios were very low and cylinder temperatures were relatively low as compared to high load conditions. The SOF made up 29 and 31 percent of the 7-mode and transient total particulate, respectively. These levels increased to 67 and 55 percent for the pilot-injected methanol configuration, due to significant SOF at light loads where mostly pilot diesel fuel was consumed. The addition of the oxidation catalyst significantly reduced the SOF contribution to total particulate, but the increase in the sulfate and the "remainder" (which is discussed in the next paragraph) kept the total particulate emissions about the same as without the catalyst. Similar to other emission trends, the spark-ignited engine emitted very little SOF, but relative to the total particulate, the SOF accounted for 59 and 75 percent of the 7-mode and transient composite particulate emissions, respectively.

The "remainder" of the total particulate (less sulfate and SOF) consists of insolubles such as carbon particles, metals, metal oxides, and other compounds, many of which may exist in a hydrated form (containing water). Significantly less carbon was noted for the emissions from the pilot-injected engine than for those from the diesel engine during the higher-power steady-state modes. Addition of the catalyst increased the "remainder", especially during the intermediate speed/100 percent load and the rated speed/100 percent load conditions. A similar increase was also noted during transient testing. Although a portion of the increase noted for the "remainder" may be explained by abraded catalytic material and water molecules associated with various compounds, the relatively large increase noted with the catalyst cannot be fully explained.

SOF samples from the various engines were analyzed for BaP content. Brake specific BaP levels of 0.64 and 3.7 μg/kW-hr were noted for 7-mode and transient composites on the diesel engine. Analysis of SOF from pilot-ignited methanol configurations showed that 7-mode composite BaP increased to 0.86 μg/kW-hr, while the transient composite decreased to 1.7 μg/kW-hr. As with the level of SOF, the BaP decreased to 0.08 and 0.33 μg/kW-hr over the 7-mode and transient test procedures when the oxidation catalyst was used with the pilot-injected engine. BaP levels from the spark-ignited engine were 0.06 and 0.03 μg/kW-hr for the 7-mode and transient test procedures, respectively. The noted reduction in BaP was likely due to the absence of diesel fuel combustion.

Ames testing of the SOF derived from use of methanol in the pilot-injected engine indicated a lower brake specific mutagenic potential than observed for SOF derived from the conventional diesel engine. Use of the catalyst with the methanol-fueled pilot-injected engine reduced the brake specific activity of the SOF even further over steady-state operation, but significantly increased the brake specific activity over transient operation. Ames testing of the SOF from the spark-ignited catalyst engine indicated a very low level of brake specific mutagenic potential compared to both the diesel and pilot-injected engines.

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APPENDIX A

THIRTEEN-MODE FTP TEST RESULTS

TABLE A-1. 13-MODE EMISSIONS CYCLE

```
                       M*A*N-RECHENZENTRUM              MA'HINFNDURCHLAUF AM 16.11.81

                       NAME DES BENUTZERS: HERZOG

                                          13 STUFEN ZYKLUS FUER NESELMOTOREN

                                              TAG DER MESSUNG:1 .11.81

                  MOTOR TYPE: D2566FMUH                                 MOTOR NUMMER:3949124

                  BAROMETERSTAND: 740 TORR                              REL.LUFTFEUCHTIGKEIT: 50.0 PROZ.

                  SPEZ.KRAFTSTOFFGEWICHT:0.796                          PRUEFSTANDSNR.: 10

                  MESSMETHODE FUER NO: NDIR

                  BEMERKUNGEN:EPS 16.5 ZYKLUS 5 MIN

      N    LAST    NE     BE      BKR   LUFTVOL  LAMBDA  RAUCH   AR  LIEFGR  CO    NO     HC   CO*WF   NO*WF  HC*WF     CO    NO    HC
  (U/MIN)  (N)    (KW) (G/KWH) (KG/H)  (M3/H)    (-)   (BOSCH) (%)   (%)  (PPM) (PPM) (PPMC) (G/KWH)(G/KWH)(G/KWH) (G/KG)(G/KG)(G/KG)

     500    8.0    0.4 9973.5    4.0   147.2    2.920    0.0   0.0   86.3   100    19    111   0.02    0.00   0.01     4.0   0.8   2.4

    1600   72.0   11.5 1535.5   17.7   463.5    2.073    0.0   0.0   84.6   150    19     93   0.10    0.01   0.03     4.2   0.6   1.4
    1600  206.0   33.0  737.4   24.3   476.1    1.550    0.0   0.0   86.9   150    58     54   0.10    0.04   0.02     3.1   1.2   0.6
    1600  412.0   65.9  534.8   35.3   483.7    1.036    0.0   0.0   86.3   150   253     42   0.10    0.18   0.02     2.1   3.7   0.3
    1600  625.0  100.0  488.8   48.9   476.1    0.771    0.0   0.0   86.9   100   923     33   0.07    0.60   0.01     1.0   9.0   0.2
    1600  836.0  133.8  463.8   64.7   475.0    0.581    0.0   0.0   86.7    50  1336     15   0.03    0.82   0.01     0.4   9.3   0.1

     500    7.0    0.3     -     3.8   147.2    3.053    0.0   0.0   86.0   100     0    105   0.02    0.00   0.01     4.2   0.0   2.3

    2200  669.0  147.2  521.7   76.8   649.3    0.669    0.0   0.0   86.2   100  1240     15   0.09    1.07   0.01     0.8  10.3   0.1
    2200  503.0  110.7  548.4   60.7   652.3    0.851    0.0   0.0   86.6   100   775     15   0.09    0.70   0.01     1.1   8.5   0.1
    2200  334.0   73.5  632.5   46.5   650.8    1.108    0.0   0.0   86.4   100   272     36   0.09    0.25   0.02     1.5   4.0   0.3
    2200  166.0   36.5  927.5   33.9   645.5    1.508    0.0   0.0   85.7   100    58     60   0.09    0.06   0.03     2.0   1.2   0.7
    2200  115.0   25.3 1191.5   30.1   662.9    1.740    0.0   0.0   86.0   100    39     69   0.10    0.04   0.04     2.4   1.0   0.9

     500    7.0    0.3     -     3.9   147.2    2.959    0.0   0.0   86.0   100     0    138   0.02    0.00   0.01     4.1   0.0   3.0

         BSHC =  0.23 G/KWH          BSCO =  0.92 G/KWH         BSNO   3.77 G/KWH          BSNO2 =  5.78 G/KWH

         SUMME AUS KOHLENWASSERSTOFFEN UND STICKSTOFFDIOXYD                  6.01 G/KWH

         AUS 1/2-,3/4-,1/1-LAST GEMITTELTER SPEZ.KRAFTSTOFFVERBRAUCH       535.01 G/KWH

         MITTLERE SPEZIFISCHE ABGASTRUEBUNG                                  0.00 G/KWH

         AUS 1/2-,3/4-,1/1-LAST GEMITTELTE SCHWAERZUNGSZAHL                  0.00 BOSCH
```

TABLE A-2. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATALYST
TEST-1 FUEL: EM-490-F PROJECT: 05-6619-002

BAROMETER 28.93
DATE: 1/12/82

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 527.	0.	.0	.072	2.97	4.3	.920	160.	60.	2.25	23.	14.	10.	6.	1
2	2	INTER / 1600.	15.	2.5	.250	9.49	5.6	.938	188.	103.	2.56	45.	50.	52.	37.	2
3	25	INTER / 1600.	194.	32.5	.392	9.38	6.9	.972	44.	48.	3.98	150.	12.	25.	127.	3
4	50	INTER / 1600.	388.	65.0	.574	8.99	4.9	.934	25.	28.	5.84	560.	7.	14.	474.	4
5	75	INTER / 1600.	582.	97.5	.786	9.00	3.8	.919	19.	26.	8.11	1125.	6.	13.	939.	5
6	100	INTER / 1600.	777.	130.2	1.042	9.02	4.0	.927	10.	32.	11.30	1185.	3.	15.	941.	6
7		IDLE / 554.	0.	.0	.066	3.09	3.5	.887	140.	40.	2.14	25.	12.	6.	7.	7
8	100	RATED / 2200.	627.	144.4	1.248	12.49	4.0	.922	12.	22.	9.55	1350.	5.	15.	1519.	8
9	75	RATED / 2200.	471.	108.4	.976	12.45	4.1	.921	21.	22.	7.36	1035.	8.	15.	1182.	9
10	50	RATED / 2200.	313.	72.2	.772	12.36	4.6	.920	27.	26.	5.53	530.	11.	19.	637.	10
11	25	RATED / 2200.	157.	36.2	.546	12.24	4.1	.905	50.	38.	4.18	220.	18.	26.	247.	11
12	2	RATED / 2200.	14.	3.1	.394	12.20	4.5	.905	96.	48.	3.06	100.	34.	32.	110.	12
13		IDLE / 540.	0.	.0	.068	3.06	3.9	.897	150.	52.	2.04	31.	13.	9.	9.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	CALCULATED GRAMS/KW-HR HC	CALCULATED GRAMS/KW-HR CO	CALCULATED GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	3.21	2.31	1.45	******	******	*****	.0243	.1546	.157	.956	.0244	.6	.985	*****	.067	1
2	3.33	3.48	2.49	20.00	20.88	14.98	.0265	.1546	.171	.950	.0278	4.7	1.000	6.004	.080	2
3	.52	1.05	5.40	.38	.76	3.91	.0421	.1546	.272	.925	.0422	.1	.996	.727	.080	3
4	.21	.42	13.76	.11	.22	7.29	.0641	.1546	.415	.895	.0607	-5.3	.995	.532	.080	4
5	.12	.28	19.91	.06	.14	9.63	.0877	.1546	.567	.860	.0825	-5.9	.994	.487	.080	5
6	.05	.25	15.05	.02	.12	7.22	.1159	.1546	.750	.816	.1117	-3.7	1.000	.480	.080	6
7	2.95	1.62	1.66	******	******	*****	.0214	.1546	.138	.958	.0232	8.6	.992	*****	.067	7
8	.07	.20	20.29	.03	.10	10.52	.1003	.1546	.649	.840	.0959	-4.4	1.012	.512	.080	8
9	.14	.26	20.18	.08	.14	10.90	.0787	.1546	.509	.872	.0754	-4.2	1.013	.533	.080	9
10	.24	.41	13.75	.15	.26	8.83	.0628	.1546	.406	.900	.0577	-8.2	1.018	.631	.080	10
11	.56	.79	7.54	.51	.72	6.81	.0448	.1546	.290	.922	.0442	-1.3	1.020	.886	.080	11
12	1.45	1.36	4.67	10.93	10.32	35.31	.0324	.1546	.210	.942	.0328	1.1	1.022	7.400	.080	12
13	3.31	2.21	2.16	******	******	*****	.0223	.1546	.144	.960	.0222	-.4	.991	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- =	.271	GRAM/KW-HR	(.202	GRAM/BHP-HR)
BSCO ------- =	.360	GRAM/KW-HR	(.268	GRAM/BHP-HR)
BSNOX ------ =	9.004	GRAM/KW-HR	(6.717	GRAM/BHP-HR)
BSHC + BSNOX =	9.275	GRAM/KW-HR	(6.919	GRAM/BHP-HR)
CORR. BSFC - =	.616	KG/KW-HR	(1.014	LBS/BHP-HR)

TABLE A-2 (Cont'd). 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATALYST
TEST-1 FUEL: EM-490-F PROJECT: 05-6619-002

BAROMETER 28.93
DATE: 1/12/82

MODE	TOTAL FUEL KG/MIN	DIESEL PART KG/MIN	ALCOHOL PART KG/MIN	WATER PART KG/MIN	EQIV. DIESEL KG/MIN	FUEL MOLE WEIGHT	HC KWET FACTOR	Y WATER INTAKE	F/A RATIO MASS FUEL	F/A RATIO FUEL CARBON	F/A RATIO EQIV. DIESEL	EXHAUST OXYGEN PERCENT
1	.0718	.0000	.0718	.0000	.0330	32.0433	.9562	.0070	.0243	.0243	.0112	
2	.2502	.0000	.2502	.0000	.1151	32.0433	.9502	.0091	.0265	.0265	.0122	
3	.3923	.0000	.3923	.0000	.1805	32.0433	.9252	.0112	.0421	.0421	.0194	
4	.5737	.0000	.5737	.0000	.2640	32.0433	.8950	.0078	.0641	.0641	.0295	
5	.7861	.0000	.7861	.0000	.3618	32.0433	.8605	.0060	.0877	.0877	.0404	
6	1.0416	.0000	1.0416	.0000	.4793	32.0433	.8159	.0064	.1159	.1159	.0533	
7	.0658	.0000	.0658	.0000	.0303	32.0433	.9583	.0057	.0214	.0214	.0098	
8	1.2479	.0000	1.2479	.0000	.5743	32.0433	.8397	.0064	.1003	.1003	.0462	
9	.9758	.0000	.9758	.0000	.4491	32.0433	.8716	.0067	.0787	.0787	.0362	
10	.7725	.0000	.7725	.0000	.3555	32.0433	.9001	.0074	.0628	.0628	.0289	
11	.5457	.0000	.5457	.0000	.2511	32.0433	.9224	.0066	.0448	.0448	.0206	
12	.3938	.0000	.3938	.0000	.1812	32.0433	.9417	.0072	.0324	.0324	.0149	
13	.0680	.0000	.0680	.0000	.0313	32.0433	.9601	.0063	.0223	.0223	.0103	

TABLE A-3. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATAYST
TEST-2 FUEL:EM-490-F PROJECT:05-6619-002
BAROMETER:28.95
DATE:1/22/82

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 500.	0.	.0	.064	2.74	10.3	1.011	248.	99.	2.14	35.	20.	15.	9.	1
2	2	INTER / 1600.	14.	2.3	.246	9.00	10.3	1.018	530.	965.	2.30	55.	146.	507.	47.	2
3	25	INTER / 1600.	186.	31.1	.385	9.00	10.3	1.013	85.	54.	3.98	170.	23.	27.	141.	3
4	50	INTER / 1600.	374.	62.7	.571	9.03	10.3	1.009	50.	28.	5.92	600.	14.	14.	498.	4
5	75	INTER / 1600.	566.	94.8	.766	9.00	10.3	.999	30.	24.	8.21	1110.	9.	12.	891.	5
6	100	INTER / 1600.	753.	126.1	1.039	8.57	10.3	.989	10.	32.	11.43	1275.	3.	15.	998.	6
7		IDLE / 500.	0.	.0	.067	2.67	10.3	.999	98.	40.	1.66	40.	11.	8.	14.	7
8	100	RATED / 2200.	613.	141.2	1.240	12.21	10.3	.994	19.	28.	9.88	1305.	7.	18.	1410.	8
9	75	RATED / 2200.	460.	105.9	1.000	12.17	10.3	1.000	44.	26.	8.11	1140.	17.	17.	1210.	9
10	50	RATED / 2200.	304.	70.0	.768	12.17	10.3	1.005	65.	32.	6.00	610.	24.	21.	672.	10
11	25	RATED / 2200.	152.	35.0	.576	12.21	10.3	1.012	112.	30.	4.52	260.	41.	20.	285.	11
12	2	RATED / 2200.	14.	3.1	.406	11.81	10.3	1.016	216.	86.	3.18	110.	76.	57.	120.	12
13		IDLE / 500.	0.	.0	.069	2.70	10.3	1.011	1008.	459.	1.99	40.	88.	77.	11.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	CALCULATED GRAMS/KW-HR HC	CALCULATED GRAMS/KW-HR CO	CALCULATED GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	5.19	3.98	2.31	******	******	*****	.0237	.1546	.153	.957	.0234	-1.3	.997	*****	.067	1
2	9.89	34.40	3.22	64.13	223.10	20.89	.0276	.1546	.178	.953	.0264	-4.4	1.009	6.430	.080	2
3	1.00	1.18	6.11	.75	.88	4.54	.0433	.1546	.280	.925	.0422	-2.4	1.008	.737	.080	3
4	.41	.41	14.53	.22	.23	7.93	.0638	.1546	.413	.893	.0615	-3.6	1.007	.542	.080	4
5	.19	.26	19.40	.09	.12	9.41	.0859	.1546	.556	.858	.0835	-2.9	1.009	.481	.080	5
6	.05	.24	16.01	.02	.12	7.91	.1225	.1546	.792	.813	.1128	-7.9	1.009	.490	.080	6
7	2.64	2.09	3.43	******	******	*****	.0252	.1546	.163	.966	.0181	-28.1	1.001	*****	.067	7
8	.10	.25	18.96	.05	.13	9.98	.1025	.1546	.663	.834	.0989	-3.6	1.021	.516	.080	8
9	.28	.28	20.17	.16	.16	11.42	.0830	.1546	.537	.859	.0825	-.5	1.020	.555	.080	9
10	.53	.47	14.57	.35	.31	9.59	.0637	.1546	.412	.891	.0623	-2.2	1.022	.644	.080	10
11	1.18	.58	8.23	1.16	.57	8.13	.0476	.1546	.308	.915	.0477	.1	1.021	.967	.080	11
12	3.13	2.34	4.92	24.36	18.24	38.33	.0347	.1546	.225	.938	.0342	-1.4	1.019	7.651	.080	12
13	21.39	18.74	2.68	******	******	*****	.0258	.1546	.167	.959	.0231	-10.4	.999	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = .683 GRAM/KW-HR (.509 GRAM/BHP-HR)
BSCO ------- = 1.181 GRAM/KW-HR (.881 GRAM/BHP-HR)
BSNOX ------ = 9.370 GRAM/KW-HR (6.990 GRAM/BHP-HR)
BSHC + BSNOX = 10.053 GRAM/KW-HR (7.500 GRAM/BHP-HR)
CORR. BSFC - = .630 KG/KW-HR (1.036 LBS/BHP-HR)

TABLE A-3 (Cont'd). 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATAYST BAROMETER:28.95
TEST-2 FUEL:EM-490-F PROJECT:05-6619-002 DATE:1/22/82

									F/A	RATIO		
MODE	TOTAL FUEL KG/MIN	DIESEL PART KG/MIN	ALCOHOL PART KG/MIN	WATER PART KG/MIN	EQIV. DIESEL KG/MIN	FUEL MOLE WEIGHT	HC KWET FACTOR	Y WATER INTAKE	MASS FUEL	FUEL CARBON	EQIV. DIESEL	EXHAUST OXYGEN PERCENT
1	.0642	.0000	.0642	.0000	.0296	32.0433	.9569	.0166	.0237	.0237	.0109	
2	.2457	.0000	.2457	.0000	.1130	32.0433	.9529	.0166	.0276	.0276	.0127	
3	.3855	.0000	.3855	.0000	.1774	32.0433	.9245	.0166	.0433	.0433	.0199	
4	.5707	.0000	.5707	.0000	.2626	32.0433	.8927	.0166	.0638	.0638	.0294	
5	.7657	.0000	.7657	.0000	.3524	32.0433	.8577	.0166	.0859	.0859	.0396	
6	1.0385	.0000	1.0385	.0000	.4779	32.0433	.8130	.0166	.1225	.1225	.0564	
7	.0665	.0000	.0665	.0000	.0306	32.0433	.9664	.0166	.0252	.0252	.0116	
8	1.2396	.0000	1.2396	.0000	.5705	32.0433	.8339	.0166	.1025	.1025	.0472	
9	1.0000	.0000	1.0000	.0000	.4602	32.0433	.8591	.0166	.0830	.0830	.0382	
10	.7680	.0000	.7680	.0000	.3534	32.0433	.8913	.0166	.0637	.0637	.0293	
11	.5760	.0000	.5760	.0000	.2651	32.0433	.9154	.0166	.0476	.0476	.0219	
12	.4059	.0000	.4059	.0000	.1868	32.0433	.9383	.0166	.0347	.0347	.0160	
13	.0688	.0000	.0688	.0000	.0317	32.0433	.9594	.0166	.0258	.0258	.0119	

TABLE A-4. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATALYST (AFTER)   BAROMETER: 29.20
TEST- 3   FUEL: EM-490-F   PROJECT: 05-6619-002   DATE: 2/24/82

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 500.	0.	.0	.060	2.73	11.2	1.041	76.	40.	2.14	38.	6.	6.	9.	1
2	2	INTER / 1600.	14.	2.3	.246	9.20	11.2	1.047	159.	84.	2.56	47.	42.	42.	39.	2
3	25	INTER / 1600.	191.	32.0	.399	9.20	11.2	1.037	38.	40.	4.18	186.	10.	20.	153.	3
4	50	INTER / 1600.	378.	63.4	.556	9.20	11.2	1.025	19.	30.	5.92	650.	5.	15.	526.	4
5	75	INTER / 1600.	570.	95.5	.785	9.20	11.2	1.012	13.	28.	8.41	1155.	4.	14.	929.	5
6	100	INTER / 1600.	761.	127.5	1.031	8.78	11.2	.998	7.	44.	11.18	1320.	2.	21.	1048.	6
7		IDLE / 500.	0.	.0	.054	2.68	11.2	1.015	65.	50.	2.09	47.	5.	7.	10.	7
8	100	RATED / 2200.	605.	139.4	1.210	12.03	11.2	1.005	5.	34.	9.66	1275.	2.	22.	1376.	8
9	75	RATED / 2200.	458.	105.6	.986	11.99	11.2	1.013	14.	38.	7.55	1005.	6.	26.	1131.	9
10	50	RATED / 2200.	301.	69.4	.797	11.99	11.2	1.022	20.	40.	5.92	555.	8.	28.	643.	10
11	25	RATED / 2200.	152.	35.0	.566	11.95	11.2	1.029	35.	62.	4.45	235.	13.	41.	257.	11
12	2	RATED / 2200.	14.	3.1	.402	11.95	11.2	1.036	96.	52.	3.42	107.	31.	32.	108.	12
13		IDLE / 500.	0.	.0	.060	2.70	11.2	1.041	65.	50.	2.09	35.	5.	8.	9.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	CALCULATED GRAMS/KW-HR HC	CALCULATED GRAMS/KW-HR CO	CALCULATED GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	1.61	1.63	2.54	******	******	*****	.0224	.1546	.145	.957	.0232	3.4	.986	*****	.067	1
2	2.83	2.84	2.61	18.38	18.48	16.98	.0271	.1546	.175	.949	.0277	2.3	.995	6.537	.080	2
3	.43	.83	6.38	.32	.62	4.77	.0439	.1546	.284	.921	.0442	.7	.996	.750	.080	3
4	.16	.44	15.75	.08	.23	8.29	.0612	.1546	.396	.892	.0615	.5	.997	.528	.080	4
5	.08	.29	19.71	.04	.14	9.73	.0863	.1546	.559	.855	.0853	-1.2	.999	.494	.080	5
6	.03	.34	16.95	.02	.17	8.22	.1187	.1546	.768	.816	.1106	-6.8	.998	.486	.080	6
7	1.41	2.08	3.21	******	******	*****	.0203	.1546	.131	.957	.0226	11.7	.994	*****	.067	7
8	.03	.31	18.95	.01	.16	9.87	.1017	.1546	.658	.837	.0969	-4.8	1.014	.514	.080	8
9	.09	.44	19.10	.05	.25	10.70	.0832	.1546	.538	.867	.0772	-7.2	1.012	.554	.080	9
10	.16	.59	13.45	.11	.41	9.28	.0673	.1546	.435	.893	.0615	-8.6	1.009	.684	.080	10
11	.37	1.22	7.57	.36	1.18	7.34	.0479	.1546	.310	.916	.0469	-2.1	1.012	.959	.080	11
12	1.30	1.32	4.47	10.07	10.22	34.53	.0340	.1546	.220	.934	.0365	7.3	1.010	7.642	.080	12
13	1.41	2.08	2.39	******	******	*****	.0226	.1546	.146	.958	.0226	-.1	.987	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

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BSHC -------- =   .201  GRAM/KW-HR   (  .150  GRAM/BHP-HR )
BSCO -------- =   .414  GRAM/KW-HR   (  .309  GRAM/BHP-HR )
BSNOX ------- =  9.259  GRAM/KW-HR   ( 6.907  GRAM/BHP-HR )
BSHC + BSNOX  =  9.460  GRAM/KW-HR   ( 7.057  GRAM/BHP-HR )
CORR. BSFC -- =   .632   KG/KW-HR    ( 1.039  LBS/BHP-HR  )
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TABLE A-4 (Cont'd). 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATALYST (AFTER) BARОMETER: 29.20
TEST-3 FUEL: EM-490-F PROJECT: 05-6619-002 DATE: 2/24/82

MODE	TOTAL FUEL KG/MIN	DIESEL PART KG/MIN	ALCOHOL PART KG/MIN	WATER PART KG/MIN	EQIV. DIESEL KG/MIN	FUEL MOLE WEIGHT	HC KWET FACTOR	Y WATER INTAKE	F/A RATIO MASS FUEL	F/A RATIO FUEL CARBON	F/A RATIO EQIV. DIESEL	EXHAUST OXYGEN PERCENT
1	.0605	.0000	.0605	.0000	.0278	32.0433	.9566	.0180	.0224	.0224	.0103	
2	.2464	.0000	.2464	.0000	.1134	32.0433	.9490	.0180	.0271	.0271	.0125	
3	.3991	.0000	.3991	.0000	.1837	32.0433	.9209	.0180	.0439	.0439	.0202	
4	.5563	.0000	.5563	.0000	.2560	32.0433	.8924	.0180	.0612	.0612	.0281	
5	.7853	.0000	.7853	.0000	.3614	32.0433	.8546	.0180	.0863	.0863	.0397	
6	1.0310	.0000	1.0310	.0000	.4745	32.0433	.8162	.0180	.1187	.1187	.0546	
7	.0537	.0000	.0537	.0000	.0247	32.0433	.9574	.0180	.0203	.0203	.0093	
8	1.2101	.0000	1.2101	.0000	.5569	32.0433	.8368	.0180	.1017	.1017	.0468	
9	.9864	.0000	.9864	.0000	.4539	32.0433	.8674	.0180	.0832	.0832	.0383	
10	.7974	.0000	.7974	.0000	.3670	32.0433	.8926	.0180	.0673	.0673	.0309	
11	.5661	.0000	.5661	.0000	.2605	32.0433	.9164	.0180	.0479	.0479	.0221	
12	.4021	.0000	.4021	.0000	.1851	32.0433	.9337	.0180	.0340	.0340	.0157	
13	.0605	.0000	.0605	.0000	.0278	32.0433	.9576	.0180	.0226	.0226	.0104	

TABLE A-5. 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATALYST (BEFORE) BAROMETER: 29.20
TEST- 3 FUEL: EM-490-F PROJECT: 05-6619-002 DATE: 2/24/82

MODE	POWER PCT	ENGINE SPEED COND / RPM	TORQUE OBS N X M	POWER OBS KW	FUEL FLOW KG/MIN	AIR FLOW KG/MIN	INTAKE HUMID G/KG	NOX CORR FACT	MEASURED HC PPM	MEASURED CO PPM	MEASURED CO2 PCT	MEASURED NOX PPM	CALCULATED GRAMS / HOUR HC	CALCULATED GRAMS / HOUR CO	CALCULATED GRAMS / HOUR NOX	MODE
1		IDLE / 500.	0.	.0	.060	2.73	11.2	1.041	4540.	2090.	1.34	38.	367.	328.	10.	1
2	2	INTER / 1600.	14.	2.3	.246	9.20	11.2	1.047	3400.	2577.	1.80	45.	946.	1380.	40.	2
3	25	INTER / 1600.	191.	32.0	.399	9.20	11.2	1.037	1744.	1826.	3.73	186.	479.	932.	156.	3
4	50	INTER / 1600.	378.	63.4	.556	9.20	11.2	1.025	704.	778.	5.61	650.	198.	394.	540.	4
5	75	INTER / 1600.	570.	95.5	.785	9.20	11.2	1.012	624.	407.	8.21	1155.	180.	201.	939.	5
6	100	INTER / 1600.	761.	127.5	1.031	8.78	11.2	.998	276.	694.	10.81	1305.	83.	344.	1062.	6
7		IDLE / 500.	0.	.0	.054	2.68	11.2	1.015	4540.	1953.	1.30	47.	334.	280.	11.	7
8	100	RATED / 2200.	605.	139.4	1.210	12.03	11.2	1.005	72.	273.	9.33	1275.	29.	185.	1419.	8
9	75	RATED / 2200.	453.	104.4	.986	11.99	11.2	1.013	672.	329.	7.45	1005.	264.	225.	1130.	9
10	50	RATED / 2200.	301.	69.4	.797	11.99	11.2	1.022	880.	642.	5.68	540.	351.	460.	635.	10
11	25	RATED / 2200.	152.	35.0	.566	11.95	11.2	1.029	1728.	1625.	3.92	210.	649.	1130.	240.	11
12	2	RATED / 2200.	14.	3.1	.402	11.95	11.2	1.036	3200.	1888.	2.35	86.	****	1384.	104.	12
13		IDLE / 500.	0.	.0	.060	2.70	11.2	1.041	4540.	2162.	1.34	35.	366.	338.	9.	13

MODE	CALCULATED GRAMS/KG-FUEL HC	CALCULATED GRAMS/KG-FUEL CO	CALCULATED GRAMS/KG-FUEL NOX	CALCULATED GRAMS/KW-HR HC	CALCULATED GRAMS/KW-HR CO	CALCULATED GRAMS/KW-HR NOX	F/A DRY MEAS	F/A STOICH	"PHI"	WET HC CORR FACT	F/A CALC	F/A PCT MEAS	POWER CORR FACT	BSFC CORR KG/KW-HR	MODAL WEIGHT FACTOR	MODE
1	*****	90.43	2.70	******	******	*****	.0224	.1546	.145	.969	.0220	-1.7	.986	*****	.067	1
2	63.97	93.32	2.68	416.15	607.08	17.41	.0271	.1546	.175	.960	.0262	-3.4	.995	6.537	.080	2
3	20.01	38.92	6.51	14.95	29.08	4.87	.0439	.1546	.284	.926	.0436	-.7	.996	.750	.080	3
4	5.94	11.79	16.19	3.13	6.21	8.52	.0612	.1546	.396	.897	.0601	-1.8	.997	.528	.080	4
5	3.81	4.27	19.93	1.88	2.11	9.84	.0863	.1546	.559	.857	.0846	-2.0	.999	.494	.080	5
6	1.34	5.56	17.17	.65	2.70	8.33	.1187	.1546	.768	.821	.1083	-8.7	.998	.486	.080	6
7	*****	86.82	3.43	******	******	*****	.0203	.1546	.131	.970	.0214	5.8	.994	*****	.067	7
8	.40	2.55	19.55	.21	1.33	10.18	.1017	.1546	.658	.841	.0942	-7.4	1.014	.514	.080	8
9	4.46	3.80	19.09	2.53	2.16	10.82	.0832	.1546	.538	.869	.0774	-6.9	1.012	.560	.080	9
10	7.33	9.61	13.27	5.06	6.63	9.15	.0673	.1546	.435	.896	.0608	-9.5	1.009	.684	.080	10
11	19.10	33.26	7.06	18.54	32.29	6.85	.0479	.1546	.310	.924	.0453	-5.5	1.012	.959	.080	11
12	51.00	57.36	4.29	393.73	442.88	33.14	.0340	.1546	.220	.951	.0310	-8.9	1.010	7.642	.080	12
13	*****	93.21	2.48	******	******	*****	.0226	.1546	.146	.969	.0221	-2.3	.987	*****	.067	13

CYCLE COMPOSITE USING 13-MODE WEIGHT FACTORS

BSHC ------- = 7.891 GRAM/KW-HR (5.887 GRAM/BHP-HR)
BSCO ------- = 11.053 GRAM/KW-HR (8.245 GRAM/BHP-HR)
BSNOX ------ = 9.361 GRAM/KW-HR (6.983 GRAM/BHP-HR)
BSHC + BSNOX = 17.252 GRAM/KW-HR (12.870 GRAM/BHP-HR)
CORR. BSFC - = .633 KG/KW-HR (1.041 LBS/BHP-HR)

TABLE A-5 (Cont'd). 13-MODE FEDERAL DIESEL EMISSION CYCLE 1979

ENGINE: M.A.N. METHANOL ENGINE WITH CATALYST (BEFORE) BAROMETER: 29.20
TEST-3 FUEL: EM-490-F PROJECT: 05-6619-002 DATE: 2/24/82

MODE	TOTAL FUEL KG/MIN	DIESEL PART KG/MIN	ALCOHOL PART KG/MIN	WATER PART KG/MIN	EQIV. DIESEL KG/MIN	FUEL MOLE WEIGHT	HC KWET FACTOR	Y WATER INTAKE	F/A RATIO MASS FUEL	F/A RATIO FUEL CARBON	F/A RATIO EQIV. DIESEL	EXHAUST OXYGEN PERCENT
1	.0605	.0000	.0605	.0000	.0278	32.0433	.9691	.0180	.0224	.0224	.0103	
2	.2464	.0000	.2464	.0000	.1134	32.0433	.9599	.0180	.0271	.0271	.0125	
3	.3991	.0000	.3991	.0000	.1837	32.0433	.9265	.0180	.0439	.0439	.0202	
4	.5563	.0000	.5563	.0000	.2560	32.0433	.8965	.0180	.0612	.0612	.0281	
5	.7853	.0000	.7853	.0000	.3614	32.0433	.8571	.0180	.0863	.0863	.0397	
6	1.0310	.0000	1.0310	.0000	.4745	32.0433	.8205	.0180	.1187	.1187	.0546	
7	.0537	.0000	.0537	.0000	.0247	32.0433	.9698	.0180	.0203	.0203	.0093	
8	1.2101	.0000	1.2101	.0000	.5569	32.0433	.8413	.0180	.1017	.1017	.0468	
9	.9864	.0000	.9864	.0000	.4539	32.0433	.8686	.0180	.0832	.0832	.0383	
10	.7974	.0000	.7974	.0000	.3670	32.0433	.8957	.0180	.0673	.0673	.0309	
11	.5661	.0000	.5661	.0000	.2605	32.0433	.9236	.0180	.0479	.0479	.0221	
12	.4021	.0000	.4021	.0000	.1851	32.0433	.9508	.0180	.0340	.0340	.0157	
13	.0605	.0000	.0605	.0000	.0278	32.0433	.9690	.0180	.0226	.0226	.0104	

APPENDIX B

TRANSIENT TEST RESULTS

TABLE B-1. TRANSIENT POWER MAP FROM THE M.A.N. D2566 FMUH METHANOL ENGINE

Speed rpm	Torque N•m	Speed rpm	Torque N•m
400	738	1500	743
500	768	1600	742
600	793	1700	723
700	678	1800	690
800	796	1900	671
900	759	2000	648
1000	692	2100	608
1100	777	2200	572
1200	779	2300	343
1300	769	2400	0
1400	764		

Idle Speed 500

Transient Command Cycle Power, kW hr

NYNF	LANF	LAF	NYNF	Total
1.14	1.75	5.11	1.13	9.14

TABLE B-2. ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-15 RUN1
DATE 2/10/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 744.47 MM HG(29.31 IN HG)
DRY BULB TEMP. 20.6 DEG C(69.0 DEG F)

RELATIVE HUMIDITY , ENGINE-62. PCT , CVS-18. PCT
ABSOLUTE HUMIDITY 9.6 GM/KG(67.1 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.8	299.8	304.9	297.8
TOT. BLOWER RATE SCMM (SCFM)	33.43 (1180.5)	33.44 (1180.9)	33.46 (1181.6)	33.44 (1180.7)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.93)	.05 (1.93)	.05 (1.93)	.05 (1.93)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	165.1 (5830.)	167.4 (5910.)	170.3 (6014.)	166.2 (5870.)
HC SAMPLE METER/RANGE/PPM	12.2/12/ 24.	7.4/12/ 15.	6.3/12/ 13.	3.9/12/ 8.
HC BCKGRD METER/RANGE/PPM	9.7/ 1/ 10.	11.0/ 1/ 11.	11.2/ 1/ 11.	12.7/ 1/ 13.
CO SAMPLE METER/RANGE/PPM	28.8/13/ 26.	6.8/13/ 6.	7.5/13/ 7.	5.3/13/ 5.
CO BCKGRD METER/RANGE/PPM	1.7/13/ 2.	1.6/13/ 1.	1.5/13/ 1.	1.4/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	34.9/ 3/ .58	45.4/ 3/ .78	85.1/ 3/ 1.58	29.9/ 3/ .49
CO2 BCKGRD METER/RANGE/PCT	3.0/ 3/ .05	3.1/ 3/ .05	3.1/ 3/ .05	3.0/ 3/ .05
NOX SAMPLE METER/RANGE/PPM	3.0/14/ 30.	4.8/14/ 48.	14.2/14/ 142.	3.6/14/ 36.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.7/ 2/ 1.	.1/ 3/ 0.	.3/ 2/ 0.
DILUTION FACTOR	22.75	17.15	8.49	27.06
HC CONCENTRATION PPM	15.	4.	3.	-4.
CO CONCENTRATION PPM	25.	5.	5.	3.
CO2 CONCENTRATION PCT	.54	.73	1.53	.45
NOX CONCENTRATION PPM	29.2	47.4	141.4	36.0
HC MASS GRAMS	1.44	.43	.27	-.42
CO MASS GRAMS	4.72	.91	1.06	.68
CO2 MASS GRAMS	1632.3	2250.8	4783.2	1368.6
NOX MASS GRAMS	9.22	15.16	46.06	11.44
FUEL KG (LB)	1.195 (2.63)	1.640 (3.62)	3.484 (7.68)	.997 (2.20)
KW HR (HP HR)	1.14 (1.53)	1.75 (2.35)	5.17 (6.93)	1.13 (1.52)
BSHC G/KW HR (G/HP HR)	1.27 (.94)	.24 (.18)	.05 (.04)	-.37 (-.28)
BSCO G/KW HR (G/HP HR)	4.13 (3.08)	.52 (.39)	.20 (.15)	.60 (.45)
BSCO2 G/KW HR (G/HP HR)	1430.66 (1066.84)	1284.41 (957.79)	925.59 (690.21)	1207.43 (900.38)
BSNOX G/KW HR (G/HP HR)	8.09 (6.03)	8.65 (6.45)	8.91 (6.65)	10.09 (7.52)
BSFC KG/KW HR (LB/HP HR)	1.048 (1.722)	.936 (1.539)	.674 (1.108)	.879 (1.446)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.19 (12.33)
BSHC G/KW HR (G/HP HR)	.19 (.14)
BSCO G/KW HR (G/HP HR)	.80 (.60)
BSCO2 G/KW HR (G/HP HR)	1091. (814.)
BSNOX G/KW HR (G/HP HR)	8.91 (6.64)
BSFC KG/KW HR (LB/HP HR)	.796 (1.308)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	.71
	G/KWHR(G/HPHR)	.08 (.06)
	G/KG FUEL (G/LB FUEL)	.10 (.04)
	FILTER EFF.	79.7

TABLE B-2 (Cont'd). ENGINE EMISSION RESULTS - BAG NO_x
C-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-15 RUN1
DATE 2/10/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 744.47 MM HG(29.31 IN HG)
DRY BULB TEMP. 20.6 DEG C(69.0 DEG F)

RELATIVE HUMIDITY , ENGINE-62. PCT , CVS-18. PCT
ABSOLUTE HUMIDITY 9.6 GM/KG(67.1 GRAINS/LB)
NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.8	299.8	304.9	297.8
TOT. BLOWER RATE SCMM (SCFM)	33.43 (1180.5)	33.44 (1180.9)	33.46 (1181.6)	33.44 (1180.7)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.93)	.05 (1.93)	.05 (1.93)	.05 (1.93)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	165.1 (5830.)	167.4 (5910.)	170.3 (6014.)	166.2 (5870.)
HC SAMPLE METER/RANGE/PPM	12.2/12/ 24.	7.4/12/ 15.	6.3/12/ 13.	3.9/12/ 8.
HC BCKGRD METER/RANGE/PPM	9.7/ 1/ 10.	11.0/ 1/ 11.	11.2/ 1/ 11.	12.7/ 1/ 13.
CO SAMPLE METER/RANGE/PPM	28.8/13/ 26.	6.8/13/ 6.	7.5/13/ 7.	5.3/13/ 5.
CO BCKGRD METER/RANGE/PPM	1.7/13/ 2.	1.6/13/ 1.	1.5/13/ 1.	1.4/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	34.9/ 3/ .58	45.4/ 3/ .78	85.1/ 3/ 1.58	29.9/ 3/ .49
CO2 BCKGRD METER/RANGE/PCT	3.0/ 3/ .05	3.1/ 3/ .05	3.1/ 3/ .05	3.0/ 3/ .05
NOX SAMPLE METER/RANGE/PPM	24.4/ 2/ 24.	39.3/ 2/ 39.	38.1/ 3/ 114.	29.4/ 2/ 29.
NOX BCKGRD METER/RANGE/PPM	.5/ 2/ 1.	.7/ 2/ 1.	.1/ 3/ 0.	.3/ 2/ 0.
DILUTION FACTOR	22.75	17.15	8.49	27.06
HC CONCENTRATION PPM	15.	4.	3.	-4.
CO CONCENTRATION PPM	25.	5.	5.	3.
CO2 CONCENTRATION PCT	.54	.73	1.53	.45
NOX CONCENTRATION PPM	23.9	38.6	114.0	29.1
HC MASS GRAMS	1.44	.43	.27	-.42
CO MASS GRAMS	4.72	.91	1.06	.68
CO2 MASS GRAMS	1632.3	2250.8	4783.2	1368.6
NOX MASS GRAMS	7.55	12.37	37.14	9.25
FUEL KG (LB)	1.195 (2.63)	1.640 (3.62)	3.484 (7.68)	.997 (2.20)
KW HR (HP HR)	1.14 (1.53)	1.75 (2.35)	5.17 (6.93)	1.13 (1.52)
BSHC G/KW HR (G/HP HR)	1.27 (.94)	.24 (.18)	.05 (.04)	-.37 (-.28)
BSCO G/KW HR (G/HP HR)	4.13 (3.08)	.52 (.39)	.20 (.15)	.60 (.45)
BSCO2 G/KW HR (G/HP HR)	1430.66 (1066.84)	1284.41 (957.79)	925.59 (690.21)	1207.43 (900.38)
BSNOX G/KW HR (G/HP HR)	6.62 (4.94)	7.06 (5.26)	7.19 (5.36)	8.17 (6.09)
BSFC KG/KW HR (LB/HP HR)	1.048 (1.722)	.936 (1.539)	.674 (1.108)	.879 (1.446)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.19 (12.33)
BSHC G/KW HR (G/HP HR)	.19 (.14)
BSCO G/KW HR (G/HP HR)	.80 (.60)
BSCO2 G/KW HR (G/HP HR)	1091. (814.)
BSNOX G/KW HR (G/HP HR)	7.21 (5.38) (Bag)
BSFC KG/KW HR (LB/HP HR)	.796 (1.308)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES	
GRAMS/TEST	.71
G/KWHR(G/HPHR)	.08 (.06)
G/KG FUEL (G/LB FUEL)	.10 (.04)
FILTER EFF.	79.7

TABLE B-3. ENGINE EMISSION RESULTS
H-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-16 RUN1
DATE 2/10/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 744.73 MM HG(29.32 IN HG)
DRY BULB TEMP. 22.2 DEG C(72.0 DEG F)

RELATIVE HUMIDITY , ENGINE-54. PCT , CVS-18. PCT
ABSOLUTE HUMIDITY 9.2 GM/KG(64.6 GRAINS/LB)
NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	299.9	304.9	297.9
TOT. BLOWER RATE SCMM (SCFM)	33.70 (1189.9)	33.71 (1190.3)	33.72 (1190.6)	33.70 (1190.1)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.92)	.05 (1.92)	.05 (1.92)	.05 (1.92)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	166.5 (5878.)	168.8 (5959.)	171.6 (6060.)	167.6 (5918.)
HC SAMPLE METER/RANGE/PPM	12.9/11/ 13.	14.8/11/ 15.	15.5/11/ 16.	10.8/11/ 11.
HC BCKGRD METER/RANGE/PPM	12.9/ 1/ 13.	12.8/ 1/ 13.	12.3/ 1/ 12.	14.4/ 1/ 14.
CO SAMPLE METER/RANGE/PPM	6.8/13/ 6.	5.6/13/ 5.	8.2/13/ 7.	5.7/13/ 5.
CO BCKGRD METER/RANGE/PPM	1.7/13/ 2.	1.3/13/ 1.	.9/13/ 1.	.9/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	29.1/ 3/ .48	39.2/ 3/ .66	83.7/ 3/ 1.55	25.9/ 3/ .42
CO2 BCKGRD METER/RANGE/PCT	3.2/ 3/ .05	2.9/ 3/ .04	2.8/ 3/ .04	3.0/ 3/ .05
NOX SAMPLE METER/RANGE/PPM	10.7/13/ 32.	17.6/13/ 53.	51.1/13/ 153.	10.7/13/ 32.
NOX BCKGRD METER/RANGE/PPM	.6/ 2/ 1.	.5/ 2/ 1.	.4/ 3/ 1.	.8/ 2/ 1.
DILUTION FACTOR	27.83	20.15	8.65	31.54
HC CONCENTRATION PPM	1.	3.	5.	-3.
CO CONCENTRATION PPM	5.	4.	6.	4.
CO2 CONCENTRATION PCT	.43	.62	1.51	.38
NOX CONCENTRATION PPM	31.5	52.4	152.4	31.4
HC MASS GRAMS	.05	.26	.46	-.30
CO MASS GRAMS	.89	.76	1.28	.84
CO2 MASS GRAMS	1317.8	1917.9	4740.4	1162.5
NOX MASS GRAMS	10.04	16.91	50.01	10.07
FUEL KG (LB)	.960 (2.12)	1.397 (3.08)	3.453 (7.61)	.847 (1.87)
KW HR (HP HR)	1.15 (1.54)	1.81 (2.43)	5.20 (6.97)	1.20 (1.61)
BSHC G/KW HR (G/HP HR)	.04 (.03)	.14 (.11)	.09 (.07)	-.25 (-.19)
BSCO G/KW HR (G/HP HR)	.77 (.58)	.42 (.31)	.25 (.18)	.70 (.52)
BSCO2 G/KW HR (G/HP HR)	1147.52 (855.70)	1058.40 (789.25)	912.05 (680.12)	968.30 (722.06)
BSNOX G/KW HR (G/HP HR)	8.74 (6.52)	9.33 (6.96)	9.62 (7.18)	8.39 (6.26)
BSFC KG/KW HR (LB/HP HR)	.836 (1.375)	.771 (1.268)	.664 (1.092)	.705 (1.160)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.36 (12.55)
BSHC G/KW HR (G/HP HR)	.05 (.04)
BSCO G/KW HR (G/HP HR)	.40 (.30)
BSCO2 G/KW HR (G/HP HR)	976. (728.)
BSNOX G/KW HR (G/HP HR)	9.30 (6.93)
BSFC KG/KW HR (LB/HP HR)	.711 (1.170)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	.59
	G/KWHR(G/HPHR)	.06 (.05)
	G/KG FUEL (G/LB FUEL)	.09 (.04)
	FILTER EFF.	81.1

TABLE B-3 (Cont'd). ENGINE EMISSION RESULTS - BAG NO_x H-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-16 RUN1
DATE 2/10/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 744.73 MM HG(29.32 IN HG)
DRY BULB TEMP. 22.2 DEG C(72.0 DEG F)

RELATIVE HUMIDITY , ENGINE-54. PCT , CVS-18. PCT
ABSOLUTE HUMIDITY 9.2 GM/KG(64.6 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	299.9	304.9	297.9
TOT. BLOWER RATE SCMM (SCFM)	33.70 (1189.9)	33.71 (1190.3)	33.72 (1190.6)	33.70 (1190.1)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.92)	.05 (1.92)	.05 (1.92)	.05 (1.92)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	166.5 (5878.)	168.8 (5959.)	171.6 (6060.)	167.6 (5918.)
HC SAMPLE METER/RANGE/PPM	12.9/11/ 13.	14.8/11/ 15.	15.5/11/ 16.	10.8/11/ 11.
HC BCKGRD METER/RANGE/PPM	12.9/ 1/ 13.	12.8/ 1/ 13.	12.3/ 1/ 12.	14.4/ 1/ 14.
CO SAMPLE METER/RANGE/PPM	6.8/13/ 6.	5.6/13/ 5.	8.2/13/ 7.	5.7/13/ 5.
CO BCKGRD METER/RANGE/PPM	1.7/13/ 2.	1.3/13/ 1.	.9/13/ 1.	.9/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	29.1/ 3/ .48	39.2/ 3/ .66	83.7/ 3/ 1.55	25.9/ 3/ .42
CO2 BCKGRD METER/RANGE/PCT	3.2/ 3/ .05	2.9/ 3/ .04	2.8/ 3/ .04	3.0/ 3/ .05
NOX SAMPLE METER/RANGE/PPM	28.4/ 2/ 28.	43.4/ 2/ 43.	42.9/ 3/ 129.	24.4/ 2/ 24.
NOX BCKGRD METER/RANGE/PPM	.6/ 2/ 1.	.5/ 2/ 1.	.4/ 3/ 1.	.8/ 2/ 1.
DILUTION FACTOR	27.83	20.15	8.65	31.54
HC CONCENTRATION PPM	1.	3.	5.	-3.
CO CONCENTRATION PPM	5.	4.	6.	4.
CO2 CONCENTRATION PCT	.43	.62	1.51	.38
NOX CONCENTRATION PPM	27.8	42.9	127.6	23.6
HC MASS GRAMS	.05	.26	.46	-.30
CO MASS GRAMS	.89	.76	1.28	.84
CO2 MASS GRAMS	1317.8	1917.9	4740.4	1162.5
NOX MASS GRAMS	8.86	13.85	41.89	7.57
FUEL KG (LB)	.960 (2.12)	1.397 (3.08)	3.453 (7.61)	.847 (1.87)
KW HR (HP HR)	1.15 (1.54)	1.81 (2.43)	5.20 (6.97)	1.20 (1.61)
BSHC G/KW HR (G/HP HR)	.04 (.03)	.14 (.11)	.09 (.07)	-.25 (-.19)
BSCO G/KW HR (G/HP HR)	.77 (.58)	.42 (.31)	.25 (.18)	.70 (.52)
BSCO2 G/KW HR (G/HP HR)	1147.52 (855.70)	1058.40 (789.25)	912.05 (680.12)	968.30 (722.06)
BSNOX G/KW HR (G/HP HR)	7.71 (5.75)	7.65 (5.70)	8.06 (6.01)	6.31 (4.70)
BSFC KG/KW HR (LB/HP HR)	.836 (1.375)	.771 (1.268)	.664 (1.092)	.705 (1.160)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.36 (12.55)	
BSHC G/KW HR (G/HP HR)	.05 (.04)	
BSCO G/KW HR (G/HP HR)	.40 (.30)	
BSCO2 G/KW HR (G/HP HR)	976. (728.)	
BSNOX G/KW HR (G/HP HR)	7.71 (5.75)	(Bag)
BSFC KG/KW HR (LB/HP HR)	.711 (1.170)	

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	.59
	G/KWHR(G/HPHR)	.06 (.05)
	G/KG FUEL (G/LB FUEL)	.09 (.04)
	FILTER EFF.	81.1

TABLE B-4. ENGINE EMISSION RESULTS
C-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-17 RUN1
DATE 2/11/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 749.55 MM HG(29.51 IN HG)
DRY BULB TEMP. 20.6 DEG C(69.0 DEG F)

RELATIVE HUMIDITY , ENGINE-58. PCT , CVS-26. PCT
ABSOLUTE HUMIDITY 8.9 GM/KG(62.2 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	300.0	305.0	297.9
TOT. BLOWER RATE SCMM (SCFM)	33.66 (1188.7)	33.66 (1188.6)	33.68 (1189.3)	33.66 (1188.5)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.92)	.05 (1.92)	.05 (1.92)	.05 (1.92)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	166.3 (5872.)	168.6 (5953.)	171.5 (6056.)	167.4 (5910.)
HC SAMPLE METER/RANGE/PPM	11.9/13/ 47.	15.4/11/ 15.	13.6/11/ 14.	10.3/11/ 10.
HC BCKGRD METER/RANGE/PPM	8.7/ 1/ 9.	11.3/ 1/ 11.	11.1/ 1/ 11.	12.1/ 1/ 12.
CO SAMPLE METER/RANGE/PPM	30.6/13/ 28.	6.5/13/ 6.	6.8/13/ 6.	4.5/13/ 4.
CO BCKGRD METER/RANGE/PPM	1.2/13/ 1.	1.7/13/ 2.	1.3/13/ 1.	1.1/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	34.1/ 3/ .57	43.8/ 3/ .75	83.7/ 3/ 1.55	27.7/ 3/ .45
CO2 BCKGRD METER/RANGE/PCT	3.4/ 3/ .05	3.4/ 3/ .05	3.0/ 3/ .05	2.8/ 3/ .04
NOX SAMPLE METER/RANGE/PPM	9.1/13/ 27.	14.5/13/ 44.	45.6/13/ 137.	10.1/13/ 30.
NOX BCKGRD METER/RANGE/PPM	.9/ 2/ 1.	.9/ 2/ 1.	.6/ 2/ 1.	1.0/ 2/ 1.
DILUTION FACTOR	23.23	17.84	8.65	29.37
HC CONCENTRATION PPM	39.	5.	4.	-1.
CO CONCENTRATION PPM	27.	4.	5.	3.
CO2 CONCENTRATION PCT	.52	.70	1.51	.41
NOX CONCENTRATION PPM	26.4	42.8	136.3	29.2
HC MASS GRAMS	3.76	.46	.37	-.13
CO MASS GRAMS	5.14	.84	.97	.59
CO2 MASS GRAMS	1581.7	2159.7	4728.4	1267.3
NOX MASS GRAMS	8.41	13.79	44.70	9.35
FUEL KG (LB)	1.161 (2.56)	1.574 (3.47)	3.444 (7.59)	.923 (2.04)
KW HR (HP HR)	1.16 (1.56)	1.80 (2.41)	5.26 (7.06)	1.21 (1.62)
BSHC G/KW HR (G/HP HR)	3.23 (2.41)	.25 (.19)	.07 (.05)	-.11 (-.08)
BSCO G/KW HR (G/HP HR)	4.42 (3.30)	.47 (.35)	.18 (.14)	.49 (.37)
BSCO2 G/KW HR (G/HP HR)	1359.63 (1013.88)	1201.75 (896.14)	898.15 (669.75)	1049.04 (782.27)
BSNOX G/KW HR (G/HP HR)	7.23 (5.39)	7.68 (5.72)	8.49 (6.33)	7.74 (5.77)
BSFC KG/KW HR (LB/HP HR)	.998 (1.641)	.876 (1.440)	.654 (1.075)	.764 (1.256)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.43 (12.65)
BSHC G/KW HR (G/HP HR)	.47 (.35)
BSCO G/KW HR (G/HP HR)	.80 (.60)
BSCO2 G/KW HR (G/HP HR)	1032. (770.)
BSNOX G/KW HR (G/HP HR)	8.08 (6.03)
BSFC KG/KW HR (LB/HP HR)	.753 (1.238)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES

GRAMS/TEST	.62
G/KWHR(G/HPHR)	.07 (.05)
G/KG FUEL (G/LB FUEL)	.09 (.04)
FILTER EFF.	80.9

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                    TABLE B-4 (Cont'd).  ENGINE EMISSION RESULTS - BAG NOx                     PROJECT NO. 05-6619-002
                                                  C-TRANS.

ENGINE  NO.D-3                                TEST NO.T-17   RUN1
ENGINE  MODEL   81 M.A.N. D2566FMU            DATE  2/11/82
ENGINE 11.4 L(696. CID) L-6                   TIME                                     DIESEL   EM-490-F
CVS NO.  11                                   DYNO NO.  4                              BAG CART NO.  1

BAROMETER 749.55 MM HG(29.51 IN HG)           RELATIVE HUMIDITY ,  ENGINE-58. PCT ,  CVS-26. PCT
DRY BULB TEMP. 20.6 DEG C(69.0 DEG F)         ABSOLUTE HUMIDITY  8.9 GM/KG( 62.2 GRAINS/LB)      NOX HUMIDITY C.F. 1.0000

BAG RESULTS                                                                                        4
  BAG NUMBER                                        1                2                3          NYNF
  DESCRIPTION                                     NYNF             LANF              LAF        297.9
  TIME SECONDS                                   295.9            300.0            305.0     33.66 ( 1188.5)
  TOT. BLOWER RATE SCMM (SCFM)            33.66 ( 1188.7)  33.66 ( 1188.6)  33.68 ( 1189.3)  0.00 ( 0.00)
  TOT. 20X20 RATE SCMM (SCFM)              0.00 (   0.0)    0.00 (   0.0)    0.00(  0.0)      .05 ( 1.92)
  TOT. 90MM RATE SCMM (SCFM)                .05 ( 1.92)      .05 ( 1.92)      .05 ( 1.92)    0.00 ( 0.00)
  TOT. AUX. SAMPLE RATE SCMM (SCFM)        0.00 ( 0.00)     0.00 ( 0.00)     0.00 ( 0.00)   167.4 ( 5910.)
  TOTAL FLOW STD. CU. METRES(SCF)         166.3 (   5872.)  168.6 ( 5953.)  171.5 ( 6056.)

  HC  SAMPLE METER/RANGE/PPM              11.9/13/  47.    15.4/11/  15.    13.6/11/  14.    10.3/11/  10.
  HC  BCKGRD METER/RANGE/PPM               8.7/ 1/   9.    11.3/ 1/  11.    11.1/ 1/  11.    12.1/ 1/  12.
  CO  SAMPLE METER/RANGE/PPM              30.6/13/  28.     6.5/13/   6.     6.8/13/   6.     4.5/13/   4.
  CO  BCKGRD METER/RANGE/PPM               1.2/13/   1.     1.7/13/   2.     1.3/13/   1.     1.1/13/   1.
  CO2 SAMPLE METER/RANGE/PCT              34.1/ 3/  .57    43.8/ 3/  .75    83.7/ 3/ 1.55    27.7/ 3/  .45
  CO2 BCKGRD METER/RANGE/PCT               3.4/ 3/  .05     3.4/ 3/  .05     3.0/ 3/  .05     2.8/ 3/  .04
  NOX SAMPLE METER/RANGE/PPM              24.8/ 2/  25.    37.9/ 2/  38.    37.9/ 3/ 114.    26.4/ 2/  26.
  NOX BCKGRD METER/RANGE/PPM                .9/ 2/   1.      .9/ 2/   1.      .6/ 2/   1.     1.0/ 2/   1.

  DILUTION FACTOR                              23.23            17.84             8.65           29.37
  HC  CONCENTRATION PPM                        39.               5.               4.             -1.
  CO  CONCENTRATION PPM                        27.               4.               5.              3.
  CO2 CONCENTRATION PCT                         .52              .70             1.51             .41
  NOX CONCENTRATION PPM                        23.9             37.1            113.2            25.4

  HC  MASS GRAMS                                3.76              .46              .37            -.13
  CO  MASS GRAMS                                5.14              .84              .97             .59
  CO2 MASS GRAMS                             1581.7           2159.7           4728.4          1267.3
  NOX MASS GRAMS                                7.61            11.95            37.12            8.14
  FUEL KG (LB)                            1.161 (   2.56)  1.574 (   3.47)  3.444 (   7.59)   .923 (   2.04)
  KW HR (HP HR)                            1.16 (   1.56)   1.80 (   2.41)   5.26 (   7.06)   1.21 (   1.62)

  BSHC G/KW HR (G/HP HR)                   3.23 (   2.41)    .25 (    .19)    .07 (    .05)   -.11 (   -.08)
  BSCO G/KW HR (G/HP HR)                   4.42 (   3.30)    .47 (    .35)    .18 (    .14)    .49 (    .37)
  BSCO2 G/KW HR (G/HP HR)               1359.63 (1013.88) 1201.75 ( 896.14) 898.15 ( 669.75) 1049.04 ( 782.27)
  BSNOX G/KW HR (G/HP HR)                  6.54 (   4.88)   6.65 (   4.96)   7.05 (   5.26)   6.74 (   5.03)
  BSFC KG/KW HR (LB/HP HR)                 .998 (  1.641)   .876 (  1.440)   .654 (  1.075)   .764 (  1.256)

 TOTAL TEST RESULTS 4 BAGS                                 PARTICULATE RESULTS, TOTAL FOR 4 BAGS

                                                                                                      .62
  TOTAL KW HR (HP HR)           9.43 ( 12.65)          90MM PARTICULATE RATES    GRAMS/TEST
  BSHC  G/KW HR (G/HP HR)        .47 (   .35)                                    G/KWHR(G/HPHR)        .07  (  .05)
  BSCO  G/KW HR (G/HP HR)        .80 (   .60)                                    G/KG FUEL (G/LB FUEL) .09  (  .04)
  BSCO2 G/KW HR (G/HP HR)      1032. (  770.)                                    FILTER EFF.             80.9
  BSNOX G/KW HR (G/HP HR)       6.87 (  5.12) (Bag)
  BSFC  KG/KW HR (LB/HP HR)     .753 ( 1.238)
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                          TABLE B-5. ENGINE EMISSION RESULTS
                                       H-TRANS.                                   PROJECT NO. 05-6619-002

ENGINE  NO.D-3                                    TEST NO.T-18   RUN1
ENGINE  MODEL    81 M.A.N. D2566FMU               DATE  2/11/82
ENGINE 11.4 L(696. CID) L-6                       TIME                              DIESEL    EM-490-F
CVS NO.  11                                       DYNO NO.  4                       BAG CART NO.  1

BAROMETER 749.05 MM HG(29.49 IN HG)               RELATIVE HUMIDITY ,  ENGINE-48. PCT ,  CVS-26. PCT
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)             ABSOLUTE HUMIDITY  9.0 GM/KG( 63.2 GRAINS/LB)      NOX HUMIDITY C.F. 1.0000

BAG RESULTS
  BAG NUMBER                                 1                  2                  3                  4
  DESCRIPTION                               NYNF               LANF               LAF                NYNF
  TIME SECONDS                             295.9              300.0              305.0              297.9
  TOT. BLOWER RATE SCMM (SCFM)       34.03 ( 1201.7)    34.02 ( 1201.2)    34.04 ( 1201.9)    34.02 ( 1201.1)
  TOT. 20X20 RATE SCMM (SCFM)         0.00 (    0.0)     0.00 (    0.0)     0.00(    0.0)     0.00 ( 0.00)
  TOT. 90MM RATE SCMM (SCFM)           .06 (   1.95)      .06 (   1.95)      .06 (   1.95)      .06 (  1.95)
  TOT. AUX. SAMPLE RATE SCMM (SCFM)   0.00 (   0.00)     0.00 (   0.00)     0.00 (   0.00)     0.00 (  0.00)
  TOTAL FLOW STD. CU. METRES(SCF)    168.1 (   5936.)   170.4 (  6016.)   173.3 (  6120.)   169.2 (  5973.)

  HC   SAMPLE METER/RANGE/PPM         9.1/11/    9.     10.9/11/   11.     11.7/11/   12.      8.0/11/    8.
  HC   BCKGRD METER/RANGE/PPM        11.0/ 1/   11.     11.5/ 1/   12.     11.0/ 1/   11.     11.8/ 1/   12.
  CO   SAMPLE METER/RANGE/PPM         4.8/13/    4.      5.5/13/    5.      7.0/13/    6.      4.7/13/    4.
  CO   BCKGRD METER/RANGE/PPM         1.1/13/    1.      1.0/13/    1.       .9/13/    1.      1.0/13/    1.
  CO2  SAMPLE METER/RANGE/PCT        27.8/ 3/  .46      39.2/ 3/  .66      82.2/ 3/ 1.52     26.7/ 3/  .44
  CO2  BCKGRD METER/RANGE/PCT         2.7/ 3/  .04       2.7/ 3/  .04       2.8/ 3/  .04      2.9/ 3/  .04
  NOX  SAMPLE METER/RANGE/PPM        10.3/13/   31.     16.0/13/   48.     50.8/13/  152.      9.9/13/   30.
  NOX  BCKGRD METER/RANGE/PPM         1.3/ 2/    1.      1.0/ 2/    1.       .4/ 3/    1.       .9/ 2/    1.

  DILUTION FACTOR                          29.26              20.17               8.83              30.56
  HC   CONCENTRATION PPM                    -1.                -0.                 2.                -3.
  CO   CONCENTRATION PPM                     3.                 4.                 5.                 3.
  CO2  CONCENTRATION PCT                    .42                .62               1.48                .39
  NOX  CONCENTRATION PPM                   29.5               47.1              151.2               28.9

  HC   MASS GRAMS                          -.14               -.00                .20               -.33
  CO   MASS GRAMS                           .65                .79               1.08                .65
  CO2  MASS GRAMS                        1282.8             1945.4             4687.9             1221.5
  NOX  MASS GRAMS                          9.50              15.36              50.11               9.34
  FUEL KG (LB)                        .934 (    2.06)  1.417 (    3.12)  3.414 (    7.53)   .890 (    1.96)
  KW HR (HP HR)                       1.23 (    1.65)   1.83 (    2.45)   5.32 (    7.14)   1.30 (    1.74)

  BSHC G/KW HR (G/HP HR)              -.12 (    -.09)   -.00 (    -.00)    .04 (     .03)   -.25 (    -.19)
  BSCO G/KW HR (G/HP HR)               .53 (     .39)    .43 (     .32)    .20 (     .15)    .50 (     .37)
  BSCO2 G/KW HR (G/HP HR)          1042.55 (  777.43) 1064.81 (  794.03)  880.47 (  656.57)  941.38 (  701.99)
  BSNOX G/KW HR (G/HP HR)             7.72 (    5.76)   8.41 (    6.27)   9.41 (    7.02)   7.19 (    5.37)
  BSFC KG/KW HR (LB/HP HR)            .759 (   1.249)   .776 (   1.275)   .641 (   1.054)   .686 (   1.127)

 TOTAL TEST RESULTS 4 BAGS                          PARTICULATE RESULTS, TOTAL FOR 4 BAGS

   TOTAL KW HR (HP HR)          9.68 ( 12.98)       90MM PARTICULATE RATES    GRAMS/TEST                .57
   BSHC  G/KW HR (G/HP HR)      -.03 (  -.02)                                 G/KWHR(G/HPHR)         .06 (  .04)
   BSCO  G/KW HR (G/HP HR)       .33 (   .24)                                 G/KG FUEL (G/LB FUEL)  .09 (  .04)
   BSCO2 G/KW HR (G/HP HR)      944. (  704.)                                 FILTER EFF.               85.7
   BSNOX G/KW HR (G/HP HR)      8.71 (  6.50)
   BSFC  KG/KW HR (LB/HP HR)    .688 ( 1.130)
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TABLE B-5 (Cont'd). ENGINE EMISSION RESULTS -BAG NO$_x$
H-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-18 RUN1
DATE 2/11/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 749.05 MM HG(29.49 IN HG)
DRY BULB TEMP. 23.9 DEG C(75.0 DEG F)

RELATIVE HUMIDITY , ENGINE-48. PCT , CVS-26. PCT
ABSOLUTE HUMIDITY 9.0 GM/KG(63.2 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	300.0	305.0	297.9
TOT. BLOWER RATE SCMM (SCFM)	34.03 (1201.7)	34.02 (1201.2)	34.04 (1201.9)	34.02 (1201.1)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.06 (1.95)	.06 (1.95)	.06 (1.95)	.06 (1.95)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	168.1 (5936.)	170.4 (6016.)	173.3 (6120.)	169.2 (5973.)
HC SAMPLE METER/RANGE/PPM	9.1/11/ 9.	10.9/11/ 11.	11.7/11/ 12.	8.0/11/ 8.
HC BCKGRD METER/RANGE/PPM	11.0/ 1/ 11.	11.5/ 1/ 12.	11.0/ 1/ 11.	11.8/ 1/ 12.
CO SAMPLE METER/RANGE/PPM	4.8/13/ 4.	5.5/13/ 5.	7.0/13/ 6.	4.7/13/ 4.
CO BCKGRD METER/RANGE/PPM	1.1/13/ 1.	1.0/13/ 1.	.9/13/ 1.	1.0/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	27.8/ 3/ .46	39.2/ 3/ .66	82.2/ 3/ 1.52	26.7/ 3/ .44
CO2 BCKGRD METER/RANGE/PCT	2.7/ 3/ .04	2.7/ 3/ .04	2.8/ 3/ .04	2.9/ 3/ .04
NOX SAMPLE METER/RANGE/PPM	27.6/ 2/ 28.	43.2/ 2/ 43.	41.2/ 3/ 124.	25.5/ 2/ 26.
NOX BCKGRD METER/RANGE/PPM	1.3/ 2/ 1.	1.0/ 2/ 1.	.4/ 3/ 1.	.9/ 2/ 1.
DILUTION FACTOR	29.26	20.17	8.83	30.56
HC CONCENTRATION PPM	-1.	-0.	2.	-3.
CO CONCENTRATION PPM	3.	4.	5.	3.
CO2 CONCENTRATION PCT	.42	.62	1.48	.39
NOX CONCENTRATION PPM	26.3	42.2	122.5	24.6
HC MASS GRAMS	-.14	-.00	.20	-.33
CO MASS GRAMS	.65	.79	1.08	.65
CO2 MASS GRAMS	1282.8	1945.4	4687.9	1221.5
NOX MASS GRAMS	8.47	13.77	40.61	7.97
FUEL KG (LB)	.934 (2.06)	1.417 (3.12)	3.414 (7.53)	.890 (1.96)
KW HR (HP HR)	1.23 (1.65)	1.83 (2.45)	5.32 (7.14)	1.30 (1.74)
BSHC G/KW HR (G/HP HR)	-.12 (-.09)	-.00 (-.00)	.04 (.03)	-.25 (-.19)
BSCO G/KW HR (G/HP HR)	.53 (.39)	.43 (.32)	.20 (.15)	.50 (.37)
BSCO2 G/KW HR (G/HP HR)	1042.55 (777.43)	1064.81 (794.03)	880.47 (656.57)	941.38 (701.99)
BSNOX G/KW HR (G/HP HR)	6.88 (5.13)	7.53 (5.62)	7.63 (5.69)	6.14 (4.58)
BSFC KG/KW HR (LB/HP HR)	.759 (1.249)	.776 (1.275)	.641 (1.054)	.686 (1.127)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.68 (12.98)
BSHC G/KW HR (G/HP HR)	-.03 (-.02)
BSCO G/KW HR (G/HP HR)	.33 (.24)
BSCO2 G/KW HR (G/HP HR)	944. (704.)
BSNOX G/KW HR (G/HP HR)	7.32 (5.46) (Bag)
BSFC KG/KW HR (LB/HP HR)	.688 (1.130)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	.57
	G/KWHR(G/HPHR)	.06 (.04)
	G/KG FUEL (G/LB FUEL)	.09 (.04)
	FILTER EFF.	85.7

TABLE B-6. ENGINE EMISSION RESULTS
C-TRANS

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-19 RUN1
DATE 2/17/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 733.30 MM HG(28.87 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-55. PCT , CVS-26. PCT
ABSOLUTE HUMIDITY 11.3 GM/KG(79.3 GRAINS/LB) NOX HUMIDITY C.F. 1.0000

BAG RESULTS

BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	296.0	299.9	304.9	297.8
TOT. BLOWER RATE SCMM (SCFM)	32.90 (1161.5)	32.91 (1162.0)	32.93 (1162.7)	32.90 (1161.8)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.93)	.05 (1.93)	.05 (1.93)	.05 (1.93)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	162.6 (5740.)	164.8 (5818.)	167.6 (5918.)	163.6 (5776.)
HC SAMPLE METER/RANGE/PPM	9.8/13/ 39.	12.6/11/ 13.	11.5/11/ 12.	6.9/11/ 7.
HC BCKGRD METER/RANGE/PPM	7.5/ 1/ 8.	9.3/ 1/ 9.	9.0/ 1/ 9.	10.4/ 1/ 10.
CO SAMPLE METER/RANGE/PPM	29.7/13/ 27.	4.0/13/ 4.	4.6/13/ 4.	3.7/13/ 3.
CO BCKGRD METER/RANGE/PPM	.6/13/ 1.	.6/13/ 1.	.9/13/ 1.	.6/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	33.3/ 3/ .55	44.7/ 3/ .77	83.5/ 3/ 1.54	27.7/ 3/ .45
CO2 BCKGRD METER/RANGE/PCT	3.2/ 3/ .05	3.2/ 3/ .05	3.1/ 3/ .05	2.6/ 3/ .04
NOX SAMPLE METER/RANGE/PPM	8.8/13/ 26.	14.3/13/ 43.	44.9/13/ 135.	9.8/13/ 29.
NOX BCKGRD METER/RANGE/PPM	.7/ 2/ 1.	.8/ 2/ 1.	.4/ 3/ 1.	.6/ 2/ 1.
DILUTION FACTOR	23.87	17.46	8.68	29.39
HC CONCENTRATION PPM	32.	4.	4.	-3.
CO CONCENTRATION PPM	26.	3.	3.	3.
CO2 CONCENTRATION PCT	.51	.72	1.50	.42
NOX CONCENTRATION PPM	25.6	42.2	133.5	28.9
HC MASS GRAMS	3.01	.36	.34	-.30
CO MASS GRAMS	4.97	.58	.64	.53
CO2 MASS GRAMS	1511.7	2170.9	4604.0	1247.4
NOX MASS GRAMS	7.96	13.29	42.80	9.03
FUEL KG (LB)	1.109 (2.45)	1.581 (3.49)	3.353 (7.39)	.908 (2.00)
KW HR (HP HR)	1.12 (1.50)	1.75 (2.35)	5.12 (6.87)	1.13 (1.51)
BSHC G/KW HR (G/HP HR)	2.69 (2.01)	.21 (.15)	.07 (.05)	-.26 (-.20)
BSCO G/KW HR (G/HP HR)	4.44 (3.31)	.33 (.25)	.12 (.09)	.47 (.35)
BSCO2 G/KW HR (G/HP HR)	1351.44 (1007.77)	1238.83 (923.80)	898.70 (670.16)	1107.81 (826.09)
BSNOX G/KW HR (G/HP HR)	7.11 (5.31)	7.58 (5.65)	8.35 (6.23)	8.02 (5.98)
BSFC KG/KW HR (LB/HP HR)	.992 (1.630)	.902 (1.484)	.654 (1.076)	.807 (1.326)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.12 (12.23)
BSHC G/KW HR (G/HP HR)	.38 (.28)
BSCO G/KW HR (G/HP HR)	.74 (.55)
BSCO2 G/KW HR (G/HP HR)	1045. (780.)
BSNOX G/KW HR (G/HP HR)	8.01 (5.98)
BSFC KG/KW HR (LB/HP HR)	.762 (1.253)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES

GRAMS/TEST	.50
G/KWHR(G/HPHR)	.05 (.04)
G/KG FUEL (G/LB FUEL)	.07 (.03)
FILTER EFF.	81.3

TABLE B-6 (Cont'd). ENGINE EMISSION RESULTS - BAG NO_x

C-TRANS

PROJECT NO. 05-6619-002

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ENGINE  NO.D-3                              TEST NO.T-19   RUN1
ENGINE  MODEL   81 M.A.N. D2566FMU          DATE  2/17/82
ENGINE 11.4 L(696. CID) L-6                 TIME                                 DIESEL   EM-490-F
CVS NO.  11                                 DYNO NO.  4                          BAG CART NO.  1

BAROMETER 733.30 MM HG(28.87 IN HG)         RELATIVE HUMIDITY ,  ENGINE-55. PCT ,  CVS-26. PCT
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)       ABSOLUTE HUMIDITY 11.3 GM/KG( 79.3 GRAINS/LB)      NOX HUMIDITY C.F. 1.0000

BAG RESULTS
   BAG NUMBER                                      1                 2                  3                  4
   DESCRIPTION                                   NYNF              LANF               LAF               NYNF
   TIME SECONDS                                  296.0             299.9              304.9              297.8
   TOT. BLOWER RATE SCMM (SCFM)           32.90 ( 1161.5)   32.91 ( 1162.0)   32.93 ( 1162.7)   32.90 ( 1161.8)
   TOT. 20X20 RATE SCMM (SCFM)             0.00 (    0.0)    0.00 (    0.0)    0.00(    0.0)     0.00 (    0.00)
   TOT. 90MM RATE SCMM (SCFM)               .05 (   1.93)     .05 (   1.93)     .05 (   1.93)      .05 (   1.93)
   TOT. AUX. SAMPLE RATE SCMM (SCFM)       0.00 (   0.00)    0.00 (   0.00)    0.00 (   0.00)     0.00 (   0.00)
   TOTAL FLOW STD. CU. METRES(SCF)        162.6 (  5740.)   164.8 ( 5818.)    167.6 ( 5918.)    163.6 ( 5776.)

   HC   SAMPLE METER/RANGE/PPM             9.8/13/  39.      12.6/11/  13.      11.5/11/  12.      6.9/11/   7.
   HC   BCKGRD METER/RANGE/PPM             7.5/ 1/   8.       9.3/ 1/   9.       9.0/ 1/   9.      10.4/ 1/  10.
   CO   SAMPLE METER/RANGE/PPM            29.7/13/  27.       4.0/13/   4.       4.6/13/   4.       3.7/13/   3.
   CO   BCKGRD METER/RANGE/PPM              .6/13/   1.        .6/13/   1.        .9/13/   1.        .6/13/   1.
   CO2  SAMPLE METER/RANGE/PCT            33.3/ 3/  .55      44.7/ 3/  .77      83.5/ 3/ 1.54     27.7/ 3/  .45
   CO2  BCKGRD METER/RANGE/PCT             3.2/ 3/  .05       3.2/ 3/  .05       3.1/ 3/  .05      2.6/ 3/  .04
   NOX  SAMPLE METER/RANGE/PPM            26.5/ 2/  27.      40.2/ 2/  40.      38.7/ 3/ 116.     27.1/ 2/  27.
   NOX  BCKGRD METER/RANGE/PPM              .7/ 2/   1.        .8/ 2/   1.        .4/ 3/   1.        .6/ 2/   1.

   DILUTION FACTOR                              23.87             17.46              8.68              29.39
   HC   CONCENTRATION PPM                       32.                4.                4.                -3.
   CO   CONCENTRATION PPM                       26.                3.                3.                 3.
   CO2  CONCENTRATION PCT                       .51               .72              1.50               .42
   NOX  CONCENTRATION PPM                       25.8              39.4             115.0              26.5

   HC   MASS GRAMS                              3.01               .36               .34              -.30
   CO   MASS GRAMS                              4.97               .58               .64               .53
   CO2  MASS GRAMS                             1511.7            2170.9            4604.0            1247.4
   NOX  MASS GRAMS                              8.03             12.43             36.87               8.30
   FUEL KG (LB)                          1.109 (    2.45)   1.581 (    3.49)   3.353 (    7.39)    .908 (    2.00)
   KW HR (HP HR)                          1.12 (    1.50)    1.75 (    2.35)    5.12 (    6.87)    1.13 (    1.51)

   BSHC G/KW HR (G/HP HR)                 2.69 (    2.01)     .21 (     .15)     .07 (     .05)    -.26 (    -.20)
   BSCO G/KW HR (G/HP HR)                 4.44 (    3.31)     .33 (     .25)     .12 (     .09)     .47 (     .35)
   BSCO2 G/KW HR (G/HP HR)             1351.44 (1007.77)  1238.83 ( 923.80)  898.70 ( 670.16)  1107.81 ( 826.09)
   BSNOX G/KW HR (G/HP HR)                7.18 (    5.35)    7.09 (    5.29)    7.20 (    5.37)    7.37 (    5.49)
   BSFC KG/KW HR (LB/HP HR)               .992 (   1.630)    .902 (   1.484)    .654 (   1.076)    .807 (   1.326)

 TOTAL TEST RESULTS 4 BAGS                                 PARTICULATE RESULTS, TOTAL FOR 4 BAGS

   TOTAL KW HR (HP HR)            9.12 ( 12.23)        90MM PARTICULATE RATES    GRAMS/TEST               .50
   BSHC  G/KW HR (G/HP HR)         .38 (   .28)                                  G/KWHR(G/HPHR)        .05  (  .04)
   BSCO  G/KW HR (G/HP HR)         .74 (   .55)                                  G/KG FUEL (G/LB FUEL) .07  (  .03)
   BSCO2 G/KW HR (G/HP HR)       1045. (  780.)                                  FILTER EFF.              81.3
   BSNOX G/KW HR (G/HP HR)        7.20 (  5.37) (Bag)
   BSFC  KG/KW HR (LB/HP HR)      .762 ( 1.253)
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                              TABLE B-7.  ENGINE EMISSION RESULTS                                     PROJECT NO. 05-6619-002
                                               H-TRANS.

ENGINE   NO.D-3                                   TEST NO.T-20    RUN1
ENGINE   MODEL    81 M.A.N. D2566FMU              DATE   2/17/82
ENGINE 11.4 L(696. CID) L-6                       TIME                                    DIESEL    EM-490-F
CVS NO.  11                                       DYNO NO.  4                             BAG CART NO.  1

BAROMETER 733.04 MM HG(28.86 IN HG)               RELATIVE HUMIDITY ,  ENGINE-55. PCT ,  CVS-26. PCT
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)             ABSOLUTE HUMIDITY 11.3 GM/KG( 79.3 GRAINS/LB)      NOX HUMIDITY C.F. 1.0000

BAG RESULTS
  BAG NUMBER                                    1                   2                   3                   4
  DESCRIPTION                                 NYNF                LANF                 LAF                NYNF
  TIME SECONDS                               295.9               300.0               305.0               297.9
  TOT. BLOWER RATE SCMM (SCFM)          32.90 ( 1161.5)     32.88 ( 1161.1)     32.90 ( 1161.8)     32.90 ( 1161.7)
  TOT. 20X20 RATE SCMM (SCFM)            0.00 (   0.0)       0.00 (   0.0)       0.00(   0.0)       0.00 ( 0.00)
  TOT. 90MM RATE SCMM (SCFM)              .05 ( 1.85)         .05 ( 1.85)         .05 ( 1.85)         .05 ( 1.85)
  TOT. AUX. SAMPLE RATE SCMM (SCFM)      0.00 ( 0.00)        0.00 ( 0.00)        0.00 ( 0.00)        0.00 ( 0.00)
  TOTAL FLOW STD. CU. METRES(SCF)       162.5 (   5737.)    164.7 ( 5815.)      167.5 ( 5915.)      163.6 ( 5777.)

  HC   SAMPLE METER/RANGE/PPM            8.0/11/   8.        9.9/11/  10.       11.9/11/  12.        7.4/11/   7.
  HC   BCKGRD METER/RANGE/PPM           10.0/ 1/  10.       11.0/ 1/  11.       10.3/ 1/  10.       10.7/ 1/  11.
  CO   SAMPLE METER/RANGE/PPM            4.2/13/   4.        4.4/13/   4.        5.9/13/   5.        3.9/13/   4.
  CO   BCKGRD METER/RANGE/PPM             .4/13/   0.         .2/13/   0.         .1/13/   0.         .6/13/   1.
  CO2  SAMPLE METER/RANGE/PCT           27.7/ 3/  .45       37.8/ 3/  .64       79.4/ 3/ 1.46       27.5/ 3/  .45
  CO2  BCKGRD METER/RANGE/PCT            2.7/ 3/  .04        2.3/ 3/  .04        2.7/ 3/  .04        3.4/ 3/  .05
  NOX  SAMPLE METER/RANGE/PPM            9.7/13/  29.       15.9/13/  48.       48.5/13/ 146.       10.4/13/  31.
  NOX  BCKGRD METER/RANGE/PPM            1.4/ 2/   1.        1.3/ 2/   1.         .6/ 3/   2.        1.3/ 2/   1.

  DILUTION FACTOR                           29.38               20.99                9.18               29.62
  HC   CONCENTRATION PPM                     -2.                 -1.                  3.                 -3.
  CO   CONCENTRATION PPM                      3.                  4.                  5.                  3.
  CO2  CONCENTRATION PCT                     .42                 .60                 1.42                .40
  NOX  CONCENTRATION PPM                    27.8                46.4                144.0               29.9

  HC   MASS GRAMS                           -.16                -.05                 .26                -.28
  CO   MASS GRAMS                            .64                 .71                 .98                 .56
  CO2  MASS GRAMS                         1234.6              1819.8              4356.7              1201.3
  NOX  MASS GRAMS                           8.65               14.62               46.13                9.36
  FUEL KG (LB)                         .899 (    1.98)   1.326 (    2.92)   3.173 (    7.00)    .875 (    1.93)
  KW HR (HP HR)                        1.14 (    1.53)    1.78 (    2.39)    5.16 (    6.92)    1.13 (    1.51)

  BSHC G/KW HR (G/HP HR)               -.14 (   -.10)     -.03 (   -.02)      .05 (     .04)    -.25 (    -.18)
  BSCO G/KW HR (G/HP HR)                .56 (    .42)      .40 (     .30)      .19 (     .14)     .50 (     .37)
  BSCO2 G/KW HR (G/HP HR)           1082.13 ( 806.94)  1021.08 ( 761.42)   844.28 ( 629.58)  1066.86 ( 795.56)
  BSNOX G/KW HR (G/HP HR)              7.58 (   5.66)     8.20 (    6.12)     8.94 (    6.67)    8.31 (    6.20)
  BSFC KG/KW HR (LB/HP HR)             .788 (  1.296)     .744 (  1.223)     .615 (  1.011)    .777 (  1.277)

 TOTAL TEST RESULTS 4 BAGS                              PARTICULATE RESULTS, TOTAL FOR 4 BAGS

  TOTAL KW HR (HP HR)           9.21 ( 12.35)           90MM PARTICULATE RATES    GRAMS/TEST                    .41
  BSHC   G/KW HR (G/HP HR)      -.02 (  -.02)                                     G/KWHR(G/HPHR)           .04  (  .03)
  BSCO   G/KW HR (G/HP HR)       .31 (   .23)                                     G/KG FUEL (G/LB FUEL)    .07  (  .03)
  BSCO2  G/KW HR (G/HP HR)      935. (  697.)                                     FILTER EFF.                   81.6
  BSNOX  G/KW HR (G/HP HR)      8.55 (  6.38)
  BSFC   KG/KW HR (LB/HP HR)    .681 ( 1.120)
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TABLE B-7 (Cont'd). ENGINE EMISSION RESULTS - BAG NO_x H-TRANS.

PROJECT NO. 05-6619-002

ENGINE NO.D-3
ENGINE MODEL 81 M.A.N. D2566FMU
ENGINE 11.4 L(696. CID) L-6
CVS NO. 11

TEST NO.T-20 RUN1
DATE 2/17/82
TIME
DYNO NO. 4

DIESEL EM-490-F
BAG CART NO. 1

BAROMETER 733.04 MM HG(28.86 IN HG)
DRY BULB TEMP. 25.0 DEG C(77.0 DEG F)

RELATIVE HUMIDITY , ENGINE-55. PCT , CVS-26. PCT
ABSOLUTE HUMIDITY 11.3 GM/KG(79.3 GRAINS/LB)
NOX HUMIDITY C.F. 1.0000

BAG RESULTS				
BAG NUMBER	1	2	3	4
DESCRIPTION	NYNF	LANF	LAF	NYNF
TIME SECONDS	295.9	300.0	305.0	297.9
TOT. BLOWER RATE SCMM (SCFM)	32.90 (1161.5)	32.88 (1161.1)	32.90 (1161.8)	32.90 (1161.7)
TOT. 20X20 RATE SCMM (SCFM)	0.00 (0.0)	0.00 (0.0)	0.00(0.0)	0.00 (0.00)
TOT. 90MM RATE SCMM (SCFM)	.05 (1.85)	.05 (1.85)	.05 (1.85)	.05 (1.85)
TOT. AUX. SAMPLE RATE SCMM (SCFM)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
TOTAL FLOW STD. CU. METRES(SCF)	162.5 (5737.)	164.7 (5815.)	167.5 (5915.)	163.6 (5777.)
HC SAMPLE METER/RANGE/PPM	8.0/11/ 8.	9.9/11/ 10.	11.9/11/ 12.	7.4/11/ 7.
HC BCKGRD METER/RANGE/PPM	10.0/ 1/ 10.	11.0/ 1/ 11.	10.3/ 1/ 10.	10.7/ 1/ 11.
CO SAMPLE METER/RANGE/PPM	4.2/13/ 4.	4.4/13/ 4.	5.9/13/ 5.	3.9/13/ 4.
CO BCKGRD METER/RANGE/PPM	.4/13/ 0.	.2/13/ 0.	.1/13/ 0.	.6/13/ 1.
CO2 SAMPLE METER/RANGE/PCT	27.7/ 3/ .45	37.8/ 3/ .64	79.4/ 3/ 1.46	27.5/ 3/ .45
CO2 BCKGRD METER/RANGE/PCT	2.7/ 3/ .04	2.3/ 3/ .04	2.7/ 3/ .04	3.4/ 3/ .05
NOX SAMPLE METER/RANGE/PPM	27.8/ 2/ 28.	42.0/ 2/ 42.	41.0/ 3/ 123.	28.0/ 2/ 28.
NOX BCKGRD METER/RANGE/PPM	1.4/ 2/ 1.	1.3/ 2/ 1.	.6/ 3/ 2.	1.3/ 2/ 1.
DILUTION FACTOR	29.38	20.99	9.18	29.62
HC CONCENTRATION PPM	-2.	-1.	3.	-3.
CO CONCENTRATION PPM	3.	4.	5.	3.
CO2 CONCENTRATION PCT	.42	.60	1.42	.40
NOX CONCENTRATION PPM	26.4	40.8	121.4	26.7
HC MASS GRAMS	-.16	-.05	.26	-.28
CO MASS GRAMS	.64	.71	.98	.56
CO2 MASS GRAMS	1234.6	1819.8	4356.7	1201.3
NOX MASS GRAMS	8.22	12.84	38.89	8.37
FUEL KG (LB)	.899 (1.98)	1.326 (2.92)	3.173 (7.00)	.875 (1.93)
KW HR (HP HR)	1.14 (1.53)	1.78 (2.39)	5.16 (6.92)	1.13 (1.51)
BSHC G/KW HR (G/HP HR)	-.14 (-.10)	-.03 (-.02)	.05 (.04)	-.25 (-.18)
BSCO G/KW HR (G/HP HR)	.56 (.42)	.40 (.30)	.19 (.14)	.50 (.37)
BSCO2 G/KW HR (G/HP HR)	1082.13 (806.94)	1021.08 (761.42)	844.28 (629.58)	1066.86 (795.56)
BSNOX G/KW HR (G/HP HR)	7.20 (5.37)	7.20 (5.37)	7.54 (5.62)	7.43 (5.54)
BSFC KG/KW HR (LB/HP HR)	.788 (1.296)	.744 (1.223)	.615 (1.011)	.777 (1.277)

TOTAL TEST RESULTS 4 BAGS

TOTAL KW HR (HP HR)	9.21 (12.35)
BSHC G/KW HR (G/HP HR)	-.02 (-.02)
BSCO G/KW HR (G/HP HR)	.31 (.23)
BSCO2 G/KW HR (G/HP HR)	935. (697.)
BSNOX G/KW HR (G/HP HR)	7.42 (5.53) (Bag)
BSFC KG/KW HR (LB/HP HR)	.681 (1.120)

PARTICULATE RESULTS, TOTAL FOR 4 BAGS

90MM PARTICULATE RATES		
	GRAMS/TEST	.41
	G/KWHR(G/HPHR)	.04 (.03)
	G/KG FUEL (G/LB FUEL)	.07 (.03)
	FILTER EFF.	81.6

TABLE B-8. TRANSIENT CYCLE STATISTICS AND MODAL EMISSION RATE SUMMARY

TRANSIENT CYCLE STATISTICS

	Cold Cycle			Hot Cycle		
TEST T-15 & T-16	Speed	Torque	Power	Speed	Torque	Power
Standard Error	41.	8.7	5.2	36.	8.6	5.3
Slope	1.009	0.9394	1.004	1.008	0.9225	1.007
Corr. Coef.	0.997	0.891	0.968	0.997	0.909	0.970
Intercept	2.0	-2.1	-.3	5.0	7.1	0.5
Points Used	1179	980	980	1179	996	996
Ref. Work (Dev. %)	12.25 hp-hr (-0.7%)			12.25 hp-hr (-2.5%)		
TEST T-17 & T-18						
Standard Error	41.	8.7	5.2	46.	8.6	5.3
Slope	1.009	0.9280	1.019	1.013	0.8925	1.016
Corr. Coef.	0.997	0.897	0.971	0.996	0.895	0.972
Intercept	1.6	4.6	0.3	-5.9	20.7	1.7
Points Used	1179	980	980	1179	999	999
Ref. Work (Dev. %)	12.25 hp-hr (-3.3%)			12.25 hp-hr (-5.9%)		
TEST T-19 & T-20						
Standard Error	36.	8.2	5.1	35.	8.3	5.3
Slope	1.006	0.9250	0.9969	1.006	0.9149	0.998
Corr. Coef.	0.997	0.908	0.973	0.997	0.907	0.971
Intercept	0.8	-2.6	-0.3	3.0	5.0	0.2
Points Used	1179	993	993	1179	999	999
Ref. Work (Dev. %)	12.25 hp-hr (0.17%)			12.25 hp-hr (-0.8%)		

APPENDIX C

LETTERS FROM M.A.N. TO EPA

M.A.N. MASCHINENFABRIK AUGSBURG-NÜRNBERG AKTIENGESELLSCHAFT

GESAMTBEREICH
MOTORENFORSCHUNG

United States Environmental
Protection Agency
Attn. Mr. Thomas M. Baines

Ann Arbor

Michigan 48105

Ihre Zeichen/
Nachricht vom:
Unsere Zeichen/
Nachricht vom: GFN/chm/ce/sl
☎ (09 11) 18-1
Durchwahl 18-: 2221 Chmela
Tag: 14th June 1982

M.A.N. Spark-Ignited Heavy-Duty Methanol Engine D 2566 FMUH

Dear Mr. Baines,

Thank you very much for the draft of your report on the tests on our methanol engine. We are very happy about the reasonable and altogether good results for us. In our development work of the engine we had so far concentrated on the fuel consumption. There now appear to be good hopes for further improvements on the exhaust side, especially in respect of NO_x.

We are surprised about the many failures of the ignition system of which the majority of cases have only just come to our attention. The fact that a defective ignition coil is involved points to the likelihood of elevated ambient temperatures and/or poor heat dissipation from the control unit, resistor and ignition coil. The heat loss is twice to three times as high as in normal car ignition equipment. For this reason the ignition equipment of our test benches is mounted on a metal plate with good heat conducting properties whereas in our buses it is arranged in the air intake. Obviously, in view of these precautionary measures,no problems have as yet been encountered with the ignition equipment of our test benches, nor in our buses in Berlin and Auckland.

It would indeed be regretted if, as we feel, the failures which are not inherent in the system might have reduced the overall impression.

...

Vorsitzender des Aufsichtsrates: Manfred Lennings. Vorstand: Otto Voisard. Vorsitzender: Gerd Wollburg, stellv. Vorsitzender: Friedrich Laußermair. Wilfried Lochte. Hans Dieter Meissner.
Wolfgang Muller. Gerhard Neipp. Adolf Schiff. Wolfram Thiele: Herbert Redlich, stellv.
Sitz der Gesellschaft ist Augsburg. Handels-Reg. Augsburg B 7591.

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Anschrift
M.A.N. Maschinenfabrik Augsburg-Nürnberg
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Katzwanger Str. 101, Nürnberg

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Expreßgut: Nbg.-Hbf.
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LZB Bayern
Nürnberg Konto 76 008 200

Postscheckkonto
Nürnberg 39 00-851

EPA, Ann Arbor

Thank you also for the "Procedures Book for Analysis" which will be valuable for our chemical department in setting up new measuring procedures.

Ihre Zeichen/
Nachricht vom:
Unsere Zeichen/
Nachricht vom:
☎ (09 11) 18-1
Durchwahl 18-
Tag:

Yours faithfully,

M.A.N. MASCHINENFABRIK AUGSBURG-NÜRNBERG
Aktiengesellschaft

i.V. i. A.

cf

M.A.N. MASCHINENFABRIK AUGSBURG-NÜRNBERG AKTIENGESELLSCHAFT

United States Environmental
Protection Agency
Attn. Mr. Charles L. Gray,
Director Emission Control
Technology Division
Ann Arbor, Michigan 48105

U.S.A.

RECEIVED JUL 26 1982

Ihre Zeichen/
Nachricht vom
Unsere Zeichen/
Nachricht vom
☎ (0911) 18-0
Durchwahl 18

GFN, chm-ri-su - Chmela
22 21

21th July 1982

Your letter to M.A.N. Truck and Bus Corp. dated May 28th, 1982

Dear Mr. Gray,

Thank you very much for the additional copy of the report on the tests made on our D 2566 FMUH methanol engine. We are very pleased with the results. As regards the NO_x-values we are sure that they can be lowered in the course of further optimization.

In our letter dtd. June 14th,1982 to Mr. Thomas M. Baines, we suspected that the failure of the ignition system components was due to faulty heat dissipation. In rechecking the parts returned from SWRI it became clear to us that the control unit had been screwed onto the engine block together with the ignition coil, as can be derived from the matching screw hole pattern on a mount at the fan-belt end of the engine and the fastening angle made by SWRI. Mounting the control unit, ignition coil and series resistor on the engine block in this manner is not allowed in view of the high temperatures and vibration acceleration existing there. Such an arrangement is not found in the ignition systems of automotive engines either. It is surprising that normal engine operation was at all possible over lengthy periods of time.

. . .

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Nürnberg (BLZ 760 100 85) 39 00-851

United States Environmental
Protection Agency, Ann Arbor

Ihre Zeichen/
Nachricht vom
Unsere Zeichen/
Nachricht vom
☎ (09 11) 18
Durchwahl 18
Tag

We regret to inform you that the results from the transient test with the 200 HP Diesel version of this engine are not available yet.

We are also of the opinion that the comparatively higher consumption values in the transient test are attributable to the maximum torque curve established by SWRI.

The engine envisaged to run with an automatic transmission is subjected to load in the vehicle only from approx 800 rpm upwards. Between 800 and 400 rpm the delivery rate approaches the excess rate needed for starting, which is approximately 30 % above the full-load delivery rate required at 800 rpm. With the maximum delivery rate available from the injection pump the specific fuel consumption in this speed range is excessively high and surely contributes to an exaggerated test and consumption figure.

We would appreciate it if your report would take our above comments into account.

Very truly yours,

M.A.N. MASCHINENFABRIK AUGSBURG-NÜRNBERG
Aktiengesellschaft

i.V.

q

Vorsitzender des Aufsichtsrates: Manfred Lennings. Vorstand: Otto Voisard, Vorsitzender; Gerd Wollburg, stellv. Vorsitzender; Friedrich Laußermair, Wilfried Lochte, Hans-Dieter Meissner, Wolfgang Müller, Gerhard Neipp, Wolfram Thiele; Herbert Redlich, stellv.
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